WORK SAMPLING

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Preface

Work Sampling, as it has come to be known, was used first by L. H. C. Tippett, the eminent British statistician, in 1935, when he applied statistical sampling to the problems of prediction of loom breakdowns in a textile mill in England.* Its first appearance in this country seems to have been about 1940, when Robert Lee Morrow described the technique which Tippett had called "a snap reading method" by the term "ratio delay study," and visualized it as a method for establishing delay allowances in connection with time study.†

The technique had widely scattered trials over the war years, but, like statistical quality control, failed to obtain general use because some elementary knowledge of statistics and probability were required for its interpretation.

C. L. Brisley, of Wolverine Tube Division of Calumet & Hecla Consolidated Copper Co., is generally credited with the origination of the expression "Work Sampling," which he introduced in an article in *Factory Management and Maintenance* in July, 1952. The term "Work Sampling" is a much better one than "ratio delay study" because it more properly describes the technique, and because it removes the limita-

* L. H. C. Tippett, "A Snap Reading Method of Making Time Studies of Machines and Operatives in Factory Surveys," *Journal of the British Textile Institute Transactions*, vol. 26, pp. 51–55, February, 1935.

† Morrow, Robert Lee, "Ratio Delay Study," 1940 Annual Meeting of the American Society of Mechanical Engineers.

tion of its use to delay allowances. This is fortunate because the use of Work Sampling for many types of quantitative analysis problems deserves wider adoption.

Over the years since 1935, many articles have been written for periodicals in the industrial engineering, industrial management, and statistical fields, but no one book has appeared up to this time which attempts to supply the most important need: basic theory and practice, in the general case. It is the hope of the authors that this book will fill this need. It is intended not only for the use of those now using Work Sampling but also as an instruction manual in training and preparation for Work Sampling.

The authors are painfully aware that their experience, while it is extensive and useful, cannot begin to encompass the entire range of experience which other engineers and managers have had in the use of Work Sampling. Any book of this type must therefore be an attempt to fill a specific need. The authors hope that it will provide the base upon which to build.

The authors wish to extend their gratitude to the many companies and individuals with whom they have been associated in the Work Sampling studies described in this book and to their preceptors, their associates at Lehigh University, and to many former students, who have all assisted in developing the authors' own understanding and appreciation of Work Sampling. In particular, valuable contributions to this work have been made by A. D. Radin and J. F. Foley, of Remington Rand Division, Sperry Rand Corporation; J. M. Kalbach, of E. I. du Pont de Nemours & Company; John Gladson, of Esso Standard Oil Co.; Robert Kanter, of the United Auto Workers, CIO-AFL; L. E. Killian and J. W. Enterline, of Armstrong Cork Co.; W. S. Masland, of C. H. Masland & Sons; Dr. M. E. Mundel, of Marquette University Management Center; W. L. Westerman, of the U.S. Army Ordnance

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Work Sampling

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What Is Work Sampling?

Work Sampling is a measurement technique for the quantitative analysis, in terms of time, of the activity of men, machines, or of any observable state or condition of operation. Work Sampling is particularly useful in the analysis of non-repetitive or irregularly occurring activity, where no complete methods and frequency description is available. It is also an extremely useful device with which to make an inexpensive over-all survey of office, shop, or service activity. Such a preliminary study can help evaluate the need for further study, and it may serve to establish a "bench mark" for managerial purposes. Because it is extremely convenient, possesses known reliability, and because it operates without recourse to the stop watch or to subjective judgments of "effort" or "performance," Work Sampling seems to be assured of wide adoption in the future.

A Work Sampling study consists of a large number of observations taken at random intervals; in taking the observations, the state or condition of the object of study is noted, and this state is classified into predefined categories of activity pertinent to the particular work situation. From the proportions of observations in each category, inferences are drawn concerning the total work activity under study. As an oversimplified example, if a group of maintenance men are observed to be "waiting" in a third of the observations made of their activity,

we might draw the inference that better scheduling or supervision, rather than increased crew size, represents the most fruitful area for improvement.

The underlying theory of Work Sampling is that the percentage of observations recording a man or machine as idle, working, or in any other condition reflects to a known degree of accuracy the average percentage of time actually spent in that state or condition. If observations are randomly distributed over a sufficiently long period of time, this theory is held to be true, regardless of the nature of the observed activity. Work Sampling observations may be likened to a series of photographs taken at random times, with the added advantage that the observer is capable of on-the-spot interpretation and classification of what he sees.

Work Sampling, as the name implies, utilizes the well-established principle of drawing inferences and establishing frames of reference from a random sample of the whole. In this case the "whole" is the total activity of the area, persons, or machines observed during the entire period of time over which observations are made. Work Sampling is a practical compromise between the extremes of purely subjective opinion and the "certainty" of continuous observation and detailed study. The advantage of Work Sampling is that the taking of a few random observations can be done economically, usually as a collateral duty of supervision, while other detailed methods of appraisal are more expensive and may require the full-time services of groups of specialists.

The exact degree of reliability of a Work Sampling study can be regulated very simply by varying the number of observations made. Fundamentally, the reliability required of any study is dependent upon the end use to which the study will be put. For example, as few as four hundred observations

may permit inferences to be drawn concerning broad areas of investigation or general courses of action. On the other hand, in order to aid in the establishment of production standards for use with incentive wage payment, several thousand observations may be needed. Relatively simple statistical methods of determining how many observations will be presented in later chapters of this book. The general rule is that as more precise information becomes necessary, more observations are required.

An essential condition of Work Sampling is that observations be taken at random. "Randomness" in the statistical sampling sense means the condition that any given instant of time has an equal likelihood of selection as the time for observation as any other instant, that there is no apparent order to the times of observation, and thus that one time of observation is independent of all other times of observation. Finally, the entire period of time over which samples are taken must be subject to selection as the random times of observation are drawn. If these conditions are met, and enough observations are taken, inferences of known reliability may be made through Work Sampling. There are several straightforward tests by which the randomness of times of observation may be verified or tested. If careful attention is paid to these tests, the accuracy and reliability of Work Sampling studies can be developed to within any practical limit. By "practical" is meant the answer, dollarwise, to the question: "How much certainty of results is desired for the expense involved?"

The reason for laying such stress on randomness of observation and the taking of a large enough number of observations is that Work Sampling is dependent on these two factors for its success. Although primarily a tool of supervision and management, some qualified advice in statistics is necessary in

most cases. The previous paragraphs are intended to point out the particular instances in which statistical theory is a matter which must be given attention.

The Place of Work Sampling in Work Measurement

When the term "work measurement" is used in describing the appraisal of industrial activity in terms of time, there is sometimes the connotation that the expression is limited to stop-watch time study or to predetermined work times. However, in this text work measurement will be applied to all techniques, however dissimilar in detail, which are used to arrive at a time value for the accomplishment of work. By far the most common applications of work measurement techniques are to be found in production jobs. This is true because such jobs must of necessity be standardized as to material, tools, and method in order to produce identical operations on the product. It therefore becomes a condition of work measurement that the exact conditions for which the standard was originally set be maintained throughout the usefulness of the standard. Brief descriptions follow of the more common techniques of work measurement. These are arranged in order of size of the elements used in measurement, in terms of time. While it is true that unusual work situations might result in changes of the relative position of the techniques listed, the order listed is correct for purposes of generalization. The techniques are as follows:

Predetermined Human Work Times. In this technique, "basic" movements of hand and body members are assigned time values, of the order of fractions of a second, and the time necessary to perform a given unit of work is built up by addition of these times. A very detailed methods description must be made in using this technique, but this is a point in its favor, since it calls attention automatically to the method while set-

ting the time allowed. This technique is valuable in detailed planning and estimating. It requires skilled personnel, and has found its greatest application in production shops with appropriate volume to justify the expense. There are many systems of predetermined human work times in use, none of which has been recognized as a standard, but most of which can be quite useful when properly applied.

Stop-watch Time Study. This is the technique most used at present in work measurement. It has been in use in production shops for over fifty years, and is the basis for most industrial time standards. In this type of measurement, a careful methods description is made of a task, the task is subdivided into elements for timing, an observer watches the task as it is performed, and notes the time taken to accomplish the task. The observer may then "rate" or "level" the observed times; this simply means that he adjusts the observed time to some sort of standard of performance. Sometimes this technique of "rating" is quite subjective and inexact. Sometimes "rating" is not done, but rather a fixed proportion of the observed time is taken as standard. In any event, it is this aspect of stop-watch time study which is most often criticized. While a great deal of this criticism is justified, the hard fact remains that for some classes of jobs no other technique has proved to be as successful. Stop-watch time study requires skilled personnel. It is sometimes a controversial technique. But it is in wide use, and will be with us for a long time.

Elemental Times or Standard Data. This technique is known by a variety of names, but very simply consists of the tabulation of elements from stop-watch time study, according to physical characteristics of the workpiece, and the building up of time standards by combining these elements. For example, if it is observed in a series of stop-watch time studies that a family of parts requires about the same time to be loaded into

a jig or fixture, this time will be used in preference to making detailed studies of similar parts. In using elemental times or standard data in this manner, less precision of result is obtained, but the expense of work measurement is also less.

Historical or Statistical Data. This method of work measurement is widely used in those work situations where it is not felt that detailed studies are justified because of variations in jobs received, or because the expense involved seems too great for the possible savings in labor and better management. Job-shop foundries, machine shops, construction companies, and maintenance and service activities use this technique. Very simply, some physical characteristic of the product or job is related to the time it has taken in the past to do jobs with similar characteristics. Thus, in a foundry such standards might be based on number of molds and tonnage. In a machine shop, they might be based on the amount of metal removed by various machines, and in an office, such standards might be based on pages of copy typed, number of invoices handled, or a similar measure. There is no detailed methods description made, but such standards are a great deal better than no standards at all. Historical or statistical data are in wide use, but are mostly used by supervision for planning gross requirements and as a rough measure of performance. Generally, these standards are not too exact, but again those employing them feel that they serve the purpose.

Self-reporting. This hardly seems an appropriate technique of work measurement to be listed with stop-watch time study and standard data. But many situations exist where the individual employee's own appraisal of the time taken or required for a job is used as a standard. This is particularly true in office and in maintenance work. Self-reporting of time spent is quite useful in some cases where labor cost is minor, and there exists no special desire for methods improvement.

Subjective Over-all Evaluation. This term may be applied to the very common situation wherein management and supervision make use of past experience and tradition to determine employee work loads. There is no measurement, in the commonly accepted sense of the word. This technique is mentioned, however, since so often it is the point of departure from which other work measurement systems are introduced.

It is immediately apparent that there exist wide differences in the given work measurement techniques. These differences occur in the areas of detail of methods description, precision of result, degree of subjective judgment, timing device used, skill and experience of technician performing the measurement, and cost of measurement. The reason for the differences is twofold, namely, differences in objectives of measurement and differences in the nature of the work being measured. Not only may the same technique be used to study different jobs, but the same job may be measured by different techniques. Thus, the selection of a "proper" work measurement technique must take into account such factors as the previous history of work measurement in the plant, the relative expense of each method, and the nature of the job itself. In a situation of this nature, hard and fast rules governing the use of each work measurement technique simply do not exist. Each management must use its own judgment in the matter. The multiplicity of types of work measurement schemes now in use testify to the fact that such exercise of judgment has taken place. The same job may be measured by stop-watch time study in one plant, by predetermined human work times in another, and by standard data in a third. Furthermore, all three methods may be successful in each particular situation. The only conclusion which may be drawn is that many of the techniques of work measurement have some versatility, and that the conditions surrounding the use of the various techniques

should be considered before an attempt is made to select the technique.

Since Work Sampling is of relatively modern origin, however, not many hard and fast rules have been developed with respect to the situations in which it may be applied. In some respects, this is a fortunate circumstance. Too many of the presently used techniques have had to live down a history of misapplication in particular factory situations before their merit was established under proper conditions. Work Sampling, however, is a self-policing technique in the sense that as the study progresses, it is possible to evaluate the reliability and validity and to determine how many observations will be required to obtain any desired level of confidence in the results. Furthermore, the major types of activity are pretty well defined in the early stages, and it is left to the director of the study to decide at what point it becomes uneconomical to pursue further detail. Under these circumstances a recommendation to "try it out and see what happens" is by no means reckless or irresponsible. Rather, it may be a sound approach, for Work Sampling is a technique peculiarly adaptable to the common management practice of making a broad survey to establish over-all conditions of operation and of following this with more detailed studies as indicated.

Perhaps the best way to indicate the versatility of Work Sampling, and at the same time to point out its limitations, is to describe some of the situations in which Work Sampling has been used. This will be done in Chap. 2. The advantages of Work Sampling over other techniques for work measurement will vary with the characteristic sought in measurement. In some cases, particularly where detailed time standards are needed, Work Sampling is not nearly as suitable a measurement tool as predetermined times or standard data. In other situations, where general shop or office effectiveness is to be

measured, Work Sampling seems to offer the best first approximation to exact measurement. In many other cases, a combination of Work Sampling and some other technique may be the best means of measurement.

Work Sampling has many attractive features as a measurement tool. It is relatively inexpensive to use. It produces results of known reliability and accuracy. It has gained wide acceptance among employees, both unionized and nonunionized. And it enables management to obtain an over-all appraisal of operations conveniently and economically. But Work Sampling, to be effective, must be done properly. Objectives must be set which are attainable through use of the technique. Management must lend its support to the studies, and must make proper use of the results. If Work Sampling is undertaken with the intention of "doing the job right," however, it offers unique opportunities for gain through good work measurement.

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Some Examples of the Use of Work Sampling

A significant aspect of the introduction of Work Sampling as a work measurement technique is that in a great number of cases Work Sampling has been used successfully in work situations which previously had not been considered susceptible of any time appraisal. This acceptance of Work Sampling has been accelerated by the industrial trend toward mechanization in production and clerical work, which in turn has led to greater expenditures in the maintenance and service fields. As a general rule, Work Sampling is a better tool for measuring the type of work classed as "indirect labor" than are time study or predetermined human work times.

Perhaps the best way to illustrate the manner in which Work Sampling has been applied is to cite some examples of its use. While the examples must be presented in abridged form in this chapter, some will be discussed in greater detail in later chapters. The following examples have been selected to illustrate the versatility of Work Sampling. It is not possible in a few pages to be completely definitive, but the reader should find at least some work situations which will enable him to establish a frame of reference for his own problem.

CASE EXAMPLE 1: *Chemical-plant Operation*

A large chemical plant included a "batch process" area in which relatively small lots were produced. For many years no appraisal had been made of the work of operating wage-roll personnel. It had been felt that direct labor represented only a small part of mill cost, and that the nature of the work was such that measurement was impractical. However, a cost-reduction program had been instituted at the plant, and it was decided to use Work Sampling to study direct-labor operating personnel.

The work was irregular in nature, and involved walking, attention to gages, manipulating valves, and keeping records. A separate maintenance group stationed a man at each operating unit to perform minor repairs as necessary. The Work Sampling study was made of operator activity. Although the maintenance men were not studied at the outset, it soon became apparent that they were acting as relief operators a substantial part of the time. Line supervision knew that this relief occurred "occasionally," but had no idea of the actual extent. Furthermore, the study revealed that practically no time was being spent in certain quality control procedures. This was undesirable.

As a result of the study, the stand-by maintenance crew was curtailed. A clerk was transferred to take care of the supervisor's routine paper work, and the supervisor was then free to spend more time in the unit and to provide better direction of operator performance. Process yield was improved and mill cost was reduced.

CASE EXAMPLE 2: *Industrial Construction*

A large construction company uses Work Sampling as the basic measure of over-all labor effectiveness. The work is typical building craft activity, dispersed over several acres and

many structures on any given construction site. While the sites vary in size, an average of four hundred employees are working on a site at a given time. A company "work sampler" is used to take observations. Most sites are unionized.

The activity studied was grouped into three main categories: useful work, work which is undesirable, and delays or activity other than work. Top management at the site received reports of these three categories. Supervision received more detailed reports. Trends were watched carefully, and in almost every case, performance improved throughout the life of the project.

The largest benefits have come through better planning and labor utilization. Undesirable work, such as rework and materials handling, has been pinpointed, and made the subject of programs for improvement. Over a period of years a bank of information has been collected which is valuable in developing cost data for estimating. Work Sampling now is accepted as the standard procedure for appraising site labor effectiveness and for labor cost control.

CASE EXAMPLE 3: *Verifying Time-study Allowances*

A medium-sized factory was engaged in the manufacture of metal moldings for the automotive trade. Two hundred and fifty unionized production workers were covered by a blanket allowance for tool setup and adjustment. Such an allowance is applied as a percentage of time added to the standard. Over a period of years it had become obvious that the time-study rates had "loosened." A restudy seemed necessary, but it was desired to include appraisal of the allowances as well as verification of the balance of the time studies. All rates were guaranteed, and could not be changed without corresponding methods change. Emphasis was placed on analyzing irregular activity in general, and tool setup and adjustment in particular.

The Work Sampling study revealed that the percentage allowance for tool setup was quite "loose." Of greater importance, a large amount of time was found to be spent in delays and in waiting for work. During this time operators were paid average incentive wages. Corrective action was taken to improve production control (scheduling) and to revise inspection practice. The allowances were made a matter of negotiation within the framework of the union contract. Work Sampling was made a continuous program, and a Control Chart technique used to help supervision control indirect-labor costs.

An interesting aspect of this study was that union shop stewards were encouraged to accompany the personnel making Work Sampling observations. This helped tremendously in gaining acceptance of the technique.

CASE EXAMPLE 4: *Railroad-yard Switch-engine Activity*

A railroad classification yard used three switch engines per shift in its operation. Capital investment in the yard was high, and efficiency in operation was essential to meet schedules. By "classification" is meant the sorting and transfer of freight cars from one train to make up another train. The yard under study had not met expectations in economy and efficiency. All employees were members of strong unions.

A Work Sampling study was made, in which switch-engine activity, conditions of trains and track, and other operating data were observed. No change was contemplated in crew size or working rules as applied to personnel.

As a result of the study, certain operating methods were revised, and one switch engine per shift was eliminated. Paper-work procedures, which the study revealed to be the cause of much delay, were streamlined. Operating costs were

reduced by removing the causes of certain delays in train movement.

An important by-product of this study was the realization on the part of management that sampling and statistical analysis techniques were applicable in many other phases of their operations. Railroad work involves large numbers of cars, bills of lading, inspection reports, tickets, and control devices. In many cases, sampling rather than complete inspection and processing seemed to offer opportunities for gain. This is now being investigated.

CASE EXAMPLE 5: *An Office Problem*

In a central accounts payable operation for a large company in the chemical industry, manual methods were used to process invoices and produce vouchers in payment. From a number of management sources came opinions that this department could be reduced from its present 25 employees, consisting of clerks and typists, by a "substantial amount" which was estimated to be upwards of 10 employees, if a punched-card procedure were installed. The department supervisor was dubious, but was unable to reach a conclusion, because he had very few facts at hand with which to measure the impact of such a change on his department operating costs and personnel utilization.

Work Sampling enabled this supervisor to reach a decision. Results of one month of observations revealed that only 15 of his employees would be affected by the proposed punched-card procedure, but that his operating budget could be reduced by 6 persons.

All observations were made by the supervisor and his assistant. No one else entered the office to make the study. No disturbance of routine was encountered.

CASE EXAMPLE 6: *A Problem in Utilization of Plant Maintenance Personnel*

A large company in the hard-surfaced floor-covering industry was contemplating a frontal attack on a major problem of long standing—maintenance and construction costs. In its largest plant, where about 650 maintenance workers were employed, the company placed a fine industrial engineer who "didn't know it couldn't be done." His task was to design and submit a program for (1) evaluating present maintenance and construction effort as to effectiveness and quality of planning and performance; and (2) achieving, in a period of from two to five years, a type of planning, control, and coordination which would stem the continued growth in maintenance and construction costs which had hitherto seemed to accompany most process improvements.

The initial program for accomplishing the first objective was spearheaded by an extensive Work Sampling program, with the observers being foremen and supervisors, 30 in number. Each of these was trained; standard uniformly applied categories were defined; and observations were recorded and processed on mark-sensed punched cards at the rate of about 40,000 man-observations per month.

After some early nonrandom influences were detected and removed, the Work Sampling provided an inexpensive, valid, and reliable estimate of time utilization. A long-range program for accomplishing the second objective—improvement—was then laid out, and Work Sampling was, and is yet, the principal device used to measure the effectiveness of the continued improvements which have followed, and are yet to come.

The most immediately obvious improvements came from the mere fact that supervisors and foremen took the time and effort to observe their own personnel objectively and made

methods and materials improvements on the spot, where obvious economies could be made!

CASE EXAMPLE 7: *A Problem in Establishing Delay Allowances for Wage Incentives*

In a medium-sized company in the electrical switchgear industry, a program for development of wage incentives to cut costs was initiated. The industrial engineer undertook a program based on standard data for machining operations, along with tool, material, and equipment standardization.

The shop had a United Steelworkers of America (CIO) local union, and union acceptance of the pace rating method was achieved through joint union-management agreement on a 100 per cent pace concept in a multi-image film loop. Later sessions brought agreement on the principle of Work Sampling for establishing allowances for nonrecurring delays throughout the shop.

After one month of Work Sampling by foremen and time-study observers, the complete range of allowance values was established, with virtually no disagreements whatever. Both union and management are very well satisfied after a year of operating with these allowances.

CASE EXAMPLE 8: *A Problem in Equipment Utilization*

In a large manufacturing company in the electronics industry, making vacuum tubes and other components, a problem in availability and adequacy of "test set" equipment arose.

A test set is a large, complex device having an operator's console, mounting positions for units to be tested, and various banks of dials, gages, and circuitry used for inspection of finished tubes and components. In some cases, a cost as high as $30,000 for such a test set is incurred.

There were three test sets available, with three operators on

each of three shifts using them. The department supervisor complained about the accumulation of completed units at the sets, in larger and larger amounts, and requested that a fourth set be acquired to relieve the apparent bottleneck.

The superintendent, on the advice of a dubious staff engineer, instituted a Work Sampling study by all three shift supervisors, each observing the three sets from 12 to 15 times per shift, at random intervals.

After one week of observations, no more sampling was required. Analysis of the results showed a 54 per cent utilization of the existing sets, and corrective action taken by the supervisors themselves increased the utilization in a period of two weeks to 81 per cent, more than could have been added by a fourth test set at the previous proportion of utilization!

The answer lay in better departmental material handling to the test sets, closer supervision, and simplified setup routines. The problem was *not* one of insufficient equipment, after all!

CASE EXAMPLE 9: *A Problem in Crane Delays*

A medium-sized company in the structural-steel fabricating industry had a large number of complaints from skilled shop layout men and fitters, working under wage incentives, about their inability to "make the rate," that is, earn a bonus.

Since the complaint was a relatively new one, while the rates were not new, the industrial engineer instituted a Work Sampling study, noting causes of delay.

Analysis of one week's results revealed that the real problem was not the rates, but an extraordinarily large proportion of delays incurred by waiting for service by the overhead bridge cranes. In tracking down the causes of these delays, it was noted that the crane operators' access to the crane cabs was located at one end of the shop; crane operators were favoring floor requirements at the end of the shop where the crane cab

access was located; crane operators and their chainmen on the floor were absent on personal time a large portion of the time, making the cranes inoperative; and a volume of work was flowing through the shop which was considerably larger than that which the number of cranes provided was intended to handle!

Note that correction of the problems could now be undertaken, since the real problems had been identified objectively!

CASE EXAMPLE 10: *A Problem in Service-station Layout*

In a large oil company, a research study was undertaken to determine the most economical layout for a service station. A team of industrial engineers was assigned the problem of obtaining reliable data on the distribution of service-station personnel time, and the distribution of customer requirements when visiting service stations.

Randomly selected stations were chosen, and Work Sampling methods were used to gather both types of data. The engineer observing a station did not interfere with the servicemen's work in any way, and simply observed their activities at random intervals. He concurrently collected data on customers' requirements by observing customers randomly chosen from a table of random numbers. Peak-and-valley cycles in station requirements then appeared as an important by-product.

As a result of this study, the oil company developed a new, improved station design, and made a major overhaul of its station servicemen's training program.

CASE EXAMPLE 11: *A Problem in Preparing for Integrated Data Processing*

A company in the textile industry undertook a program aimed at integrated data processing. A small-scale general-

purpose computer was ordered, and investigations of present procedures were initiated.

Since the present tabulating department was not functioning satisfactorily, a Work Sampling study of equipment capacity and utilization was made. This disclosed that present punched-card equipment was doing productive work slightly less than 40 per cent of the time. Further Work Sampling study of the tabulating department personnel time utilization disclosed that the supervision in the department was conspicuously poor in quality, and that both personnel and equipment were being used at a relatively low level of efficiency.

Consequently, a major program for training, retraining, better housekeeping, file survey, record retention, and equipment maintenance was carried out, and steps to improve supervision were taken, since management considered installation of a computer without efficient and well-managed tabulating facilities unthinkable.

Observations for these studies were made by the department supervisor and his assistant, whose constructive attitudes throughout made identification of trouble spots, and making of significant improvements, possible.

CASE EXAMPLE 12: *Design and Drafting Activity*

A large design organization was faced with an acute shortage of experienced engineer-designers. The organization was engaged in the design of petroleum and chemical plants. Prior to the study, the entire group had been organized on functional lines, and had been dispersed over a number of buildings. One suggestion for improvement was that composite groups be organized. In addition, it was felt that many engineers were performing work which might be done by less skilled personnel.

A Work Sampling study was made in order to measure the

then existing situation and to help appraise the gains possible. Management was not commited to change the existing situation. It was possible to subcontract some of the work, or to rely more heavily on the design sections of vendors. But in any event, it was desired that the facts of the situation be known.

The study required an unusual amount of detailed observation. Group supervisors acted as observers. Categories of activity were defined to separate skilled work from routine work. The results of the study indicated that positive steps might profitably be taken to form composite groups, rearrange work assignments, and improve reference and blueprint procedures. The changes which were made resulted in the meeting of increased work load without creating an overload on the designer-engineers.

3

Some Theory of Sampling in General

What We Do When We Sample

The idea of selecting a few items from a large number of items, in order to get some idea of the composition of the entire lot, is a very old one, probably predating recorded history. Indeed, virtually everything we do in our daily lives has some aspects of sampling in it. For example, when we buy a basket of peaches at a roadstand, we actually "take a chance" that those on top are representative of all the others we cannot see. When we eat a spoonful of Mother's soup, and announce to her its excellence, we are drawing the inference that other spoonfuls to follow will be equally satisfying. If we rig up a rope swing on a limb of a tree for a child, and test it with adult weight before allowing it to carry a child, we are really sampling its strength by applying an overload, drawing the inference *on a single sample*, that subsequent use by a much lower weight will not cause it to break. Every time we buy anything—a light bulb, an automobile, a pack of cigarettes, or any other item—we are drawing a sample of one, and we expect that one item to be representative of all other similar-looking or similarly described items. If we are dissatisfied, our *sample of one* may well cause us to change brands on our next purchase. Note here that, where repeated purchases of the "same" thing are made such as the same brand of cigarettes, we are accumulating a comparatively *large* sample as

time goes on, and have probably not found any appreciable difference from pack to pack. Nevertheless, each successive pack is really a sample of a tremendous quantity of similar packs.

It would be highly interesting, but not especially productive, to go on enumerating other examples of the sampling which we all do continually in our daily lives. It is our purpose to examine here the characteristics and behavior of samples, how we can measure and evaluate them, and how we can then use these measurements and evaluations to promote action and improvement.

Sampling, then, is the process of drawing inferences concerning the characteristics of a mass of items, by examining closely the characteristics of a somewhat smaller number of items drawn from the entire mass.

Types of Sampling Techniques

In general, there are three common methods of drawing samples:

1. Random sampling
2. Systematic sampling
3. Stratified or selective sampling

While nearly all sampling uses some degree of randomness as a condition, it is listed separately here, since the completely random sample is the most commonly used in industrial engineering work.

The concept of "randomness" is somewhat intuitive. Its precise definition is difficult, but it can be described rather easily as a method of drawing samples where *no apparent order* or connection between and/or among items is present.

The *conditions* for randomness can be simply stated. There are three:

1. Each item selected must be completely *independent* of (that is, not connected with) any other item.

2. Each item must have *equal likelihood of being selected;* i.e., no item should have a better opportunity to be drawn than any other.

3. The characteristic (of each item) being measured or described throughout the drawing of samples must remain the same; that is, an item may not change its make-up during the process of sampling.

We shall return later to these necessary conditions of randomness.

Systematic sampling is a method in which a regularly ordered interval is maintained between items chosen. For example, if we select a sample of records from a file cabinet, by choosing every tenth record, we are using systematic sampling. However, if the characteristic we are analyzing bears no relation to its order in the file, the *systematically drawn sample* may in reality produce a *randomly* distributed result in the characteristic being measured.

Selective or "stratified" sampling consists of drawing a sample (randomly and/or systematically) from a portion or portions of the entire mass of items, in order to limit the number of items drawn. Usually there is a reason why the portion or portions chosen are sufficient for the objectives desired. Stratifying a sample may, however, lead to dangerous conclusions, particularly when the stratification in sampling is not fully appreciated. A conspicuous example of this danger occurred when, during the 1936 presidential campaign, the *Literary Digest* based its opinion survey on a randomly drawn sample of telephone subscribers, thereby failing to realize that the nonsubscribers might exercise a strong influence in one direction!

These three general types of sampling methods are all com-

monly used, although there is more than a little failure to appreciate the differences in the conclusions drawn from their use.

Drawing Inferences from Samples

All sampling is performed in order to learn something. In industrial engineering work the objective in sampling is usually to *estimate* something, or to describe it adequately. Since sampling can therefore be said to lead to the making of *inferences*, it is well to stop here and consider just what an inference is, and the precision with which a measurement can be made from sampling methods.

If it were possible to measure a characteristic to absolute precision, and if all possible items containing this characteristic could be measured economically, a state of *certainty* in our knowledge concerning that characteristic could be obtained. As an example of this certainty, suppose that we have a case of 24 cans of tomato juice, and wish to find out the "average" quantity contained in a can. Assuming that we could measure with infinite precision, we might find it to be 8.01056 . . . ounces, varying among the cans from 8.0001 . . . to 8.01567 . . . . Now our knowledge concerning the contents of the case of 24 cans is, to all intents and purposes, *certainty*.

We must realize, however, that our one case may also be considered as one of a large number, say 10,000, of such cases packed in a four-week harvest season. Consequently we are not able to state with *certainty* anything about the weight of the cans in the other 9,999 cases. The average which we found, and the limits, high and low, contained in our "typical" case *may or may not* be the same as we would find if we were to follow the same procedure through all the other cases.

In this type of situation, we would expect that a measurement of a single can in our case of tomatoes would not neces-

sarily be the same as the average of our entire case of 24. Indeed, our *average* weight, found by adding up all the 24 weights and dividing by 24, may not be the actual weight of any single can in our case!

In the same manner, we would find that as our sample size increased from 1 case to 10,000 cases, our knowledge of the actual average weight per can would become closer and closer to certainty, but we would have to measure all 240,000 cans, or 10,000 cases, before this certainty could exist. As the size of the sample increases, our approach to certainty increases; and conversely, *the smaller the sample size, the smaller the degree of reliability we can attach to our result.* This is a cardinal rule of sampling.

Methods for describing the degree of uncertainty resulting from sample measurements are of several types. We shall deal with these in later chapters. The important point here is that a sampling technique will always provide an answer which must be "hedged," that is, described more or less unprecisely, and therefore containing a risk of error of some magnitude. In general, *the precision*, i.e., *nearness to certainty or truth, of the estimate made from sampling depends upon the sample size.*

While it may appear that a "hedged" answer, such as a statement that "the average weight of a can is 8.01056 . . . ounces *plus or minus* 0.05652 . . . ounce," is a rather unsatisfactory one, it is the only type which a sampling procedure can possibly provide. And experience discloses that this type of answer is preferable, since it describes its own "margin for error." Many of us—too many, perhaps—are accustomed to thinking of measurements as certainties, when they are in fact only approximations. It is good scientific thinking to consider all measures as only *approximately* true. He who intends to use Work Sampling must realize that this technique will

never provide data which can be considered in any way as certainty!

The real advantage in statistical "hedging" lies in the fact that a scientifically or mathematically determined margin for error is highly preferable to the bland assumption that any one measurement is *truth itself!*

It is noteworthy that sampling techniques behave in such a way that the more analysis and measurement is done, the greater the reliability of the result; that is, in an economic sense *you must spend more to get more.* The decision to use sampling is, in the first place, a recognition of the fact that complete measurement of all items is not economical in view of the value of the result. We therefore must, and *should*, be happy to interpret the results in their true light—a relatively inexpensive method of approximation, having measurable reliability!

Whether the practitioners realize it or not, almost *all* work measurement consists in part of the utilization of the principles of sampling. Work situations do not remain *exactly* the same. Variability may occur in materials, tools, training, operators, and surrounding conditions. For economic measurement, an "average" set of conditions is assumed, and full use is made of standard data developed in similar operations. This usually is done with full realization that when appreciable change occurs, the time standard should be adjusted. A frequent point of controversy, obviously, is in what constitutes "appreciable" change.

We are not concerned directly with this problem. It is enough to cite its existence. The literature in stop-watch time study gives ample evidence that the problem is recognized. Precautions are given to be sure that the period of observation is long enough, and statistical limits are suggested. In the use of predetermined human work times, users are cautioned to

maintain uniformity of conditions of workplace, operator, and material. The eight-hour production study is in itself a partial recognition of the fact that variability exists in the work situation. Since it is almost impossible to include all values, we must in effect sample to obtain work measurement data.

In addition to the variability of the tools and material, there exists another reason for the statement that we now resort to sampling in work measurement. This is the practice of giving "allowances" for irregularly occurring activity such as tool setting, materials handling, receiving instructions, and other similar activity which is difficult to allocate to any one unit of work or operation. Many times these allowances are determined by what is in reality a sample of one. In other instances these are almost "negotiated" allowances. The basic problem is that such irregular activity by its nature cannot be scheduled, will vary from day to day and from week to week, and yet is difficult to measure economically with stop watch or predetermined human work times. No matter what system of work measurement exists in a shop or office, it is suggested that Work Sampling will be a valuable tool in establishing these allowances. Economically, some sort of sampling seems necessary. The irregular activity is too varied and too unpredictable to allow use of continuous observation on the scale necessary.

In cases where no time standards exist, personnel and machine requirements still may have been set by a form of sampling. For example, the supervisor may know that for certain peak loads a given number of employees is required. We all tend to remember the unusual, and particularly the unusual which has been unpleasant. Therefore, the tendency may be to staff for the peak and to forget the "usual." It is suggested that Work Sampling may give a better perspective

to subjective judgment by forcing consideration of the entire cycle of activity and by analyzing this activity so that a more meaningful set of judgments may be made.

No further discussion of the concept of sampling in work measurement need be made here. The reader has only to ask himself upon what basis present decisions are made in order to realize that a form of sampling enters into present decisions. This is entirely sound, because complete consideration for measurement may be quite uneconomical. Work Sampling merely systematizes certain judgments now made subjectively in many cases.

4

Preparing for Work Sampling

The procedure for the taking of a Work Sampling study divides itself naturally into three phases. In order to place the entire procedure in proper perspective, a complete outline follows:

A. Preparing for Work Sampling
   1. Deciding upon the objectives of the study
   2. Establishing and recording quantitative measures of production with which Work Sampling results may be correlated
   3. Selection and training of personnel
   4. Announcing the fact that the study will be taken

B. Performing Work Sampling
   1. Classifying into categories the activity to be studied
   2. Designing the necessary forms
   3. Developing properly randomized times of observation
   4. Observing activity and recording data

C. Evaluating and presenting results of Work Sampling
   1. Evaluating the validity of data
   2. Evaluating the reliability of data
   3. Presenting and analyzing data
   4. Planning for future studies

While some of the above activities are more important than others, all should be considered a part of any complete study. The balance of this chapter is concerned with the first phase.

Preparing for Work Sampling

Deciding upon the Objectives of the Study. Since this book is intended to be used as a tool of management, there is no need for an extended justification of this step in the procedure. The setting of objectives has always been considered the essential first step in any managerial activity; indeed, without this, true management is impossible. Work Sampling, however, is a relatively new technique, and in thinking of specific objectives to be sought, it is well to outline first the uses to which Work Sampling can be put. The reader may then decide which particular activities in his own work situation he wishes to analyze by Work Sampling, and thus what his particular objectives will be.

Work Sampling is a very versatile measurement technique. It has the characteristic of increasing in reliability and utility of results as the number of observations made increases. For example, while it may be necessary to extend observations over a month to determine cyclic variations of specific activity, the first week's observations alone may be used immediately to check over-all performance.

A single study may thus be put to many different uses. Therefore, in determining the objectives of a Work Sampling study, a suggested list of uses may be organized in the order in which they become practical. Such a list of uses is as follows:

Uses of Work Sampling. *To Aid in Defining the Exact Problem.* Since the possible uses of Work Sampling are presented in the order in which they become practical, the first use is to combine categories of activity into very gross breakdowns, and thus to obtain an over-all index of performance. After only four hundred or so readings, for example, a good idea may be gained of the ratio of productive to nonproductive observations. In order to take specific corrective action, it is

desirable to have more detailed information. But if, in a shop, out of four hundred readings we have 60 per cent classified as productive and 40 per cent as nonproductive, the first indicated problem might be to attempt to reduce nonproductive time by instituting better production control, better materials handling, better scheduling of maintenance, and so forth. On the other hand, if the first four hundred readings show 95 per cent productive and 5 per cent nonproductive, a different problem seems to be present. Improvement probably would be directed toward better methods and equipment, at least if the shop is considered to have nonproductive time at a reasonable level.

While it may be true that with only four hundred observations we cannot have a great deal of confidence in the *exact* percentages shown, nevertheless, as a supervisor said of the first case study cited: "I don't care if that 40 per cent may be 5 per cent high or low. *Any* amount of nonproductive time spent that approaches 40 per cent is too much." In this case, management was able almost at the outset of the study to work toward the correction of an unsatisfactory condition.

Very simply, the first practical use of Work Sampling is to give advance notice, in general terms, of those activities which constitute major proportions of total activity. At the same time, management may get an indication of those categories which are of relative unimportance. While it is dangerous to draw too many inferences from a small sample, early recognition of the general problem may be gained after only a few days' observations.

To Aid in Establishing Goals for Supervision. As a general rule, real improvement and control require the cooperation of first-line supervision. As the number of observations increases, and more confidence is gained in the study, the supervisors should be "brought into the act." If the supervisor also acts

as observer, this already has been done. If someone other than the supervisor acts as observer, the supervisor should be given the opportunity to discuss results with the proper person. Therefore, the supervisor should know the basis for measuring the performance of his department or group.

The results of the study should be available, and every effort made to encourage the use of these results as a basis for corrective action or continued good practice. One of the big problems in improvement programs is to put such information into the hands of those who actually must use it. Work Sampling, as does no other measurement technique, offers the advantage that the person most capable of directing improvement may also be the person who gathers the information.

At the very least, the supervisor will have helped decide upon the categories of activity, and thus should understand the results. In the experience of the authors, *this participation by supervision is a most significant advantage of the technique of Work Sampling.* As a corollary to this, *it is obvious that management must be prepared to work with the supervisors to make changes, and that management must be prepared to have its own preconceived notions subjected to challenge!* But as more observations are obtained, better information becomes available and a more factual approach is possible.

The goals to be set generally take the form of (1) attempting to reduce the proportion of undesirable activity and (2) attempting to increase productive activity. Work Sampling provides the means of "keeping score" in many situations where detailed work measurement techniques are not effective. Some typical undesirable activities which may be measured are: waiting for work, waiting for services of all kinds, unauthorized absence, rework or corrective work, and many others. Usually, when supervision knows the nature and extent of such work, and knows it promptly, corrective action is possible.

When the monthly departmental cost report reveals extra expense, the real causes may be "buried," and in any event, it may be too late to take effective action. Most supervisors have sat through unproductive meetings intended to correct such conditions, but many of these take place weeks after the damage has been done, and generate more heat then light. With Work Sampling, it is possible to report unsatisfactory conditions in a factual quantitative manner and to measure trends of improvement.

In some cases, it is hard to decide what constitutes a "reasonable" amount of undesirable activity. No shop or office is perfect. But if it is possible to measure such activity, and to record steady improvement, to set goals for supervision in this effort is a necessity. This is particularly true when the work situation is one of an indirect-labor nature, such as maintenance, clerical, or service activity. In these fields Work Sampling offers much promise. In the shop, the various activities for which allowances are given in work measurement may be appraised in terms of percentages of observations, and these then correlated with supervisory action.

Work Sampling provides a measurement of activity which can be understood by supervision, which supervision should have had a part in obtaining, and which gives data of known reliability. This should enable the supervisor to do a better job of supervision. At the very least, the facts should now be more easily available to those responsible for the performance being measured.

To Determine the Nature and Extent of Cyclic or "Peak-load" Variations in Observable Activity. In many cases, work measurement has not been done because "the work load is not constant," or because "our work is not routine." Industrial engineers and shop foremen realize the frequent futility of developing precise time standards for job-order work. At the same

time, elemental time standards have the disadvantage that they cannot conveniently reflect variations in working conditions. Thus, overstaffing may occur, and real control becomes harder to obtain. By its very nature, however, Work Sampling is a technique which reflects changes in work-load and shop conditions. Many business and manufacturing functions are cyclic in nature. This condition is bound to be reflected in the activity of employees and equipment in these functions. But if the nature and extent of the variations are known, it is possible to *attack* the problem.

In many cases, management is aware that overstaffing exists. But in the absence of specific knowledge, there is a natural reluctance to lay off personnel who may have to be rehired almost immediately. It is possible that already available statistics will define sales fluctuations. Work Sampling should provide the other part of the story, namely, the *effect* that these fluctuations have upon the production and service facilities. In many instances, the end of the month, the end of the quarter, pay day, or other similar regularly occurring events may tend to obscure the problem of provision of proper personnel. Management *knows* that these exist! The problem is to *measure their effect.*

By virtue of the fact that several days or weeks may be required to obtain the proper number of observations, a Work Sampling study will almost automatically reveal and measure cyclic variations. Indeed, for most situations it is accepted practice to extend the Work Sampling over at least a month in order to be sure that a representative sample is obtained. If the cycle is known to be longer than a month, separate studies may be taken in busy and slack periods. It must also be remembered that no significant cyclic variations may actually exist. In this case, obvious overstaffing will become apparent. In any event, the cycle, or lack of it, should be defined by the study.

To Aid in the Economic Analysis of Equipment Needs. As more and more observations are available, it becomes possible to establish equipment usage and requirements. If one round of observations per hour is made, at the end of a month over 150 observations would be available of any single machine or item of equipment. In the case of duplicate or similar equipment this total will, of course, be greater. While records of machine utilization may exist in the production control department and elsewhere, the observed utilization is invaluable. (Incidentally, the results of the study should be compared with whatever other records exist concerning this factor.)

In some applications, such as a study of a tabulating department, the results of a Work Sampling of equipment alone, without regard to the personnel, may be of value. In other applications, the equipment may be observed and recorded as an adjunct to observing the people on the job. Measurement of such things as maintenance down time, multiple-machine operation, and idleness because of lack of material may provide an insight into shop operations, completely independent of personnel factors. By including the state or condition of equipment on the observation sheet, it is possible to add considerably to the value of the study.

While the simple proportion of time operated does not give a complete picture of the economics of equipment utilization, it does add to the facts available for use in making economic analyses. And again, the cyclic nature of demands on equipment is described and measured by Work Sampling.

To Aid in Planning Manpower Requirements. In general, the same statements which have been made concerning the economic analysis of equipment needs apply also to the planning of manpower requirements. As the study progresses and more observations lend to it a greater degree of reliability, planning of specific manpower requirements becomes prac-

tical and defensible. By this time, enough information will have been accumulated to correlate measures of production with the personnel requirements to attain each level of production. Also, such things as irregularly occurring activity and personal time will have been measured. Therefore, it should be possible to set work loads and to develop specific objectives of performance. While these may not have the accuracy of time determinations set by more detailed methods, in many instances they will be more than adequate.

To Aid in the Measurement of Over-all Performance. While this use of Work Sampling is perhaps inherent in some of the uses previously discussed, it is important enough to merit special mention. In many situations where it is not desired to embark upon a complete work measurement program of great detail, management has found that Work Sampling is a most convenient means of measuring the over-all performance of a group or activity. This generally takes the form of a Control Chart type of approach in that key categories of activity are continuously compared to prior performance or some standard. Thus, changes become easy to detect, and the effect of particular managerial action may be measured.

As an example of this, a large construction organization groups all productive work, and charts the weekly value of this group of categories. When significant changes occur in this, particularly in the unfavorable direction, the matter is almost automatically called to management's attention. Because of the reliability possible with grouping of categories, the measurement may be made quite sensitive.

This characteristic of over-all measurement is unique with Work Sampling. While over-all appraisal is *possible* with other measurement techniques, it generally either requires more work or is much less exact. Work Sampling seems to strike just the right balance between ease of gathering information and detail of results. Even though other measure-

ment techniques are used, Work Sampling may be employed for this purpose alone, to complete and verify the measurement program. In addition, Work Sampling is sometimes employed in order to give management a frame of reference to aid in making decisions concerning automation in the shop or office, management policy in personnel administration, and many other matters which require knowledge of the over-all distribution of activities of men or machines.

To Aid in the Determination of Time Standards and Allowances. This use is given last for two very strong reasons: (1) A very large number of readings are necessary in order to set specific time standards of the required precision. (2) Each time standard set requires a complete methods description in detail far greater than it may be practical to record in the typical Work Sampling study.

Furthermore, it may be considered desirable to engage in rating or leveling each operator, and this activity introduces a separate, and perhaps unknown, error* into the study. Finally, there are other methods which may be more economical to use in the establishing of individual production standards. The foregoing applies to the entire process of setting time standards. For the limited use of checking and establishing allowances for personal time, handling time, toolsetting time, cleanup time, and similar broad increments of time standards, however, Work Sampling is a most effective technique.

In establishing allowances, Work Sampling makes it possible to determine, over a long period of time, the proportions of time spent in the kinds of activity for which "blanket" adjustments are usually made. Its use for this purpose is recommended. The procedure simply requires that the fac-

* Ralph M. Barnes, and Robert B. Andrews, "Performance Sampling in Work Measurement," *The Journal of Industrial Engineering*, vol. VI, no. 6, November–December, 1955.

tors calling for an allowance be separated in the categories of observed activity and the results integrated with the existing system of setting time standards.

The basic reason for minimizing the use of Work Sampling in the setting of time standards is that, in general, it is desirable to set such standards *after the method has been improved.* With each change of method, the observations taken under the previous method may not be useful in measuring the new method. The improvement of method, selection of proper equipment, and standardization of procedures must precede the setting of standards. Thus in addition to the practical necessity of obtaining hundreds of observations of a particular job, there is the requirement that qualitative analysis and methods work be done in the proper order. It is shortsighted in the extreme to limit the objective of Work Sampling to the development of time standards of a detailed nature. It is most practical to use Work Sampling as a measuring tool for grosser activity categories, and to integrate this with more traditional measures of production, such as pieces per hour or tons per day.

When allowances are set by Work Sampling, they probably will not be as detailed in nature as those set by stop-watch time study or predetermined human work times. On the other hand, Work Sampling forces consideration of variations in materials, services, and working conditions. For that reason, allowances set by Work Sampling should reflect "typical" conditions, and should be more defensible for that reason. One of the weaknesses of standard setting by short studies is that the final standard either does not reflect variability in job conditions or depends upon some sampling technique to supply a measure of such variability.

Special Uses of Work Sampling. The preceding list of uses of Work Sampling is intended to serve as a guide to initial

studies. Also, their arrangement stresses the point that the end use of results depends upon the objectives sought and on the number of observations taken. As the user becomes more proficient and gains more confidence in the technique, he will see the possibilities for further applications.

Some specific examples of further uses of Work Sampling are as follows:

1. To help establish job content, as an aid to job evaluation. The procedure here is to define Work Sampling categories of activity in such a way that they are compatible with classifications in the job evaluation plan. Then the Work Sampling results will enable inferences to be drawn concerning the proportions of time spent under certain working conditions, exercising certain degrees of skill, or assuming certain responsibilities. These may be compared with the job descriptions as an aid in the administration of the job evaluation plan.

2. To help supervisors organize their time. This is similar to the preceding use. Either the job of the supervisor may be studied directly or the relationship of time spent by the supervisors with their men may be studied. Then the time distribution may be examined objectively to see where the supervisor needs help. For example, the common supervisory complaint of "too much paper work" can be evaluated.

3. Appraisal of safety performance. Most accidents are preventable. This prevention takes the form of periodic inspections, plus vigilance on the part of supervision. Work Sampling can be used to supplement safety inspections by the use of special codes to indicate "hazardous or unsafe working conditions."

4. Appraisal of shop effectiveness or efficiency. A Work Sampling study in itself gives some measure of shop efficiency. However, if additional subjective judgments are made to supplement the more objective categorizations, a great deal more

can be learned. While this does not mean that trained time-study raters are necessary, it is possible to get a better idea of the general level of shop performance. For instance, codes may be established to classify further the initial observations such as "working" or "handling materials." Such codes might require subjective judgments as to whether or not a job is "overmanned," whether work is done "in accordance with standard shop practice," or whether observed activity is "ineffective" or not.

Since such classification is subjective in nature, it should not override the basic activity categorization. Also, the observer should be qualified to make the judgments involved. Here the advantage of having supervisors act as observers is readily apparent.

5. Observance of specific management policy. Where management policies concern shop or office activity suitable for analysis by Work Sampling, the technique may be profitably employed to appraise the effect of such policy or the degree to which management directives are being followed. Specifically, such matters as whether or not highly skilled help performs unskilled jobs, whether machines and tools are being operated in accordance with desired practice, and many aspects of attendance and personal convenience may be appraised in terms of time.

This list could be extended almost indefinitely. The special applications usually are the outgrowth of initial studies of a straightforward and conventional nature. Once Work Sampling has been established in a company, it will find many applications unique to that company. In general, its economy and the fact that the Control Chart technique provides a sensitive measure of improvement or change have resulted in a wide variety of special uses of Work Sampling. The authors are confident that the future will bring many more.

Summary. The preceding uses of Work Sampling are expressed in broad terms. This is done in order that, in the setting of objectives of Work Sampling studies, the uses may serve as suggestions and as a guide, rather than as a "cookbook" set of rules. Each situation in which the technique is applied is different. However, those applying Work Sampling are much better situated than anyone else to appraise their own individual needs. In addition, those on the scene must *live with the results*, and should choose objectives which are practical to the particular activity to be studied. The uses given include those most commonly sought, and will serve as a guide to the statement of objective.

Establishing and Recording Quantitative Measures of Production with Which Work Sampling Results May Be Correlated. Prior to the actual taking of observations in a Work Sampling study, it is wise to agree upon some quantitative measures of output or production which may be correlated with the observed activity. Such measures of output are almost essential, as they contribute to the study in the following respects:

1. They establish an important part of the working conditions for a particular study.

2. They establish a means of correlating observable activity with recorded production. This is invaluable in planning personnel and machine requirements and for setting standards.

3. They may help answer the question: "Was the period of time over which Work Sampling was done representative of entire operations?"

In most cases, no new records need be kept. It may be necessary to segregate and preserve some records which otherwise might be destroyed, but this is not usual. The following are examples of the type of record used for the purpose under discussion:

Measure of Production	Situation under Study
Earned man-hours of production	Manufacturing department activity
Tons of steel fabricated	Structural steel shop
Number and type of tickets issued	Airline passenger reservation procedure
Number of orders filled	Stock-picking and shipping room
Dollar volume of business	Retail-store sales departments
Number of invoices received	Accounts payable office
Units of production	Machine-shop activity

The people supervising the study must decide upon the particular measure or measures which are most meaningful and which can be obtained most economically. In most cases, this should result in no additional expense, because some sort of production record is kept in most businesses. It also is desirable to record any unusual conditions or circumstances, in order to be able to analyze the results of the study and to be able to have more confidence in these results.

All this should be made a matter of discussion before the study starts, and a clear agreement should be reached that the records chosen are pertinent to the activity being measured. If there exists any doubt as to whether or not the records chosen are meaningful, it is well to keep several records and to choose among them after the results of the study are available. Usually it is difficult to go back and reconstruct records. As a by-product of the study, consideration of the reliability of such records as an indicator of manpower and machine requirements may be very profitable.

Selection and Training of Personnel. There are, in general, five groups of people involved in a Work Sampling study. Not all these groups are selected; some already hold the organizational position outlined. But all groups must be considered, since all really participate in the study.

The groups considered are as follows:

1. Management
2. Director of the study (technical advisor)

3. Line supervision
4. The observer or observers
5. The personnel being studied

Management. The function of management is to make the basic decisions involved. These include the initial decision to make the study, the selection of the director and observers, and the determination of the objectives of the study. In general, the study requires strong management support. Management should make a clear statement that it regards Work Sampling as a tool in gathering factual information to aid in the conduct of its business. This certainly is a legitimate objective of management.

At the same time it must be recognized that without management support the study may fail, or at best may not produce satisfactory results. This is true not only of Work Sampling, but also of any technique which may lead to the institution of changes in existing situations.

Management should set up the means to receive reports of the progress of the study. It should be prepared to accept these results and, if necessary, to take action. Therefore, it makes sense to give those making the study the proper degree of support necessary to ensure that the study itself is made properly, and that cooperation is obtained from all concerned.

Director of the Study. This person, the technical advisor, has the following functions:

1. In the over-all sense, to guide and supervise the study in its planning, technical details, and execution
2. To be responsible for proper reporting of results
3. In cooperation with management, to select and train observers
4. In cooperation with supervisors and observers, to define categories of activity

5. To design forms
6. To arrange for necessary data tabulation and processing
7. To perform or be responsible for statistical work as required
8. In general, to be responsible for the methods used in the conduct of the study

The director usually is selected from the industrial engineering section, from the office procedures group, or from a similar staff organization. Since Work Sampling is a fairly new technique, the person selected may not have had previous experience in its use.

The primary requisites for the director of the study are that the person selected should have the confidence of management and supervision, that he be alert, personable, and painstaking in nature, and that he have a good grasp of high school mathematics. No extended training in statistics is required, although this would, of course, be desirable. There seem to be no rigid requirements of formal education. In brief, the job requires a person who "gets things done," and who has an open mind.

The director should receive some training in statistics. The section of this book devoted to that subject will supply this training.

Line Supervision. The function of the supervisor, if he does not also act as observer, is to provide information as necessary to the observers and director. Also, he should aid in establishing the objectives and should help explain the study to his personnel. It must be kept in mind that line authority and responsibility rest in him. He should be kept informed of results, and he should understand that changes to be made may depend upon the reliability of the study.

The Observer or Observers. The fundamental worth of any system of measurement depends upon the validity and reli-

ability of the basic data. In the case of Work Sampling, these data consist of the initial observations, as classified and recorded by the observer. Therefore, unless the observers are conscientious and well instructed in their duties, Work Sampling cannot succeed. Conversely, a group of enthusiastic and competent observers can contribute tremendously to employee acceptance of Work Sampling and to the ultimate realization of the objectives of any study.

Very simply, the function of the observer is to note visually, classify into categories, and record the instantaneous state or condition of each person or machine under study. To do this, he must be familiar with the activity he observes. He may be required to move around in the area under study. He certainly will be required to exercise his judgment. He must be conscientious and without bias in the taking of observations. And finally, he should have an understanding of the methodology and objectives of Work Sampling.

Work Sampling is most useful when applied almost in its entirety by the present employees in the areas to be studied. It is much simpler and more logical to take a person who knows the shop, office, or other activity under study and to train him in Work Sampling than it is to enlist the outside "expert" to take observations and interpret results. Present employees know the personnel and can recognize them by sight. They know the equipment and are qualified to recognize unusual conditions. Furthermore, the other employees know *them*, and a freer flow of explanation and information should result from this.

The observer may be chosen from a wide variety of positions. He should, however, either be familiar with the work situation or be given time to familiarize himself with it. Three general types of observers may be used. These are:

1. Methods and measurement personnel, already engaged

in work measurement activity. This type of observer may already be engaged in time study or methods work in the area under study. Such a person is a trained man, accustomed to recognizing detail and to the classification of work activity into categories. Depending on the previous history of the actions of his group, he may have a good degree of acceptance. Such observers are most commonly used in areas such as machine shops, tabulating equipment installations, and in general areas in which they would perform work measurement by means other than Work Sampling. This last is the significant requirement. If a time-study man normally would be assigned to an area, he should make an effective observer. If time-study men are not normally in a given area, they probably will be regarded as "outsiders" and might take a long time in gaining acceptance.

2. Specially trained observers, hired for the purpose, or transferred into a full-time job as such. This type is almost an extension of the previous type. In some fields, such as construction and maintenance work, several crafts are involved and the work is done over wide geographical areas. It may be the custom in these cases to employ a "work sampler," whose task is to move around almost constantly, making observations as he goes. In some maintenance operations, he is able to make only four or five rounds a day because of the wide dispersion of people under study. Because of the craft nature of maintenance and construction work, it is sometimes desirable to use such a work sampler because immediate supervision may be oriented too much toward certain craft-union philosophies which make unbiased observation hard to obtain. This is perhaps a special case, but it exists in some situations.

3. Line supervision. Where at all possible, *it is recommended that the first-line supervisors and their assistants act as observers* or at least assist in the taking of observations. While this will create a small demand on the supervisors' time, the benefits

by far outweigh the disadvantages. Unless management is definitely dissatisfied with a supervisor's performance and does not trust him, there is no reason why he cannot be an observer. If the supervisor is too busy in scheduled meetings, etc., he may take part of the observations, and his assistant may help. Even if someone else is observer the supervisor should be encouraged to take a check study (with fewer observations, perhaps) in order to understand the technique better.

A common frequency of observations is eight per day. Many line supervisors make that many "rounds" a day in the normal course of events. In many office situations, the supervisor need not leave his desk to take observations. The authors have had many successful experiences in having supervisors take observations. To the objection that supervisors may try to influence the results favorably to themselves, the authors have found that this has happened only infrequently and has been easy to detect when it did happen, and that this risk is offset by the fact that the supervisor is quite familiar with the work, and will have tremendous confidence in the results.

As an observer, the supervisor will be able to know and explain details of the study to his people. There is no better way to help the supervisor get a measure of his own area's activity. It is axiomatic in management that *operational information is most useful when it is available immediately at the point of corrective action.* This is exactly the situation when the supervisor takes the observations. In cases where no measurement has been done before, such as in many office and service-type activities, the supervisor is most emphatically the logical one to act as observer.

Training of Observers. In discussing the training of observers, the assumption is made that the observer is familiar with the operations to be studied and is capable of recognizing activity by category and the personnel by name. The subject matter

with which the observers are to be familiarized, therefore, will consist principally of techniques. The following topics should be covered:

1. Discussion of theory of sampling and the law of large numbers. Practically speaking, the objective here is to give a simple explanation of sampling.

2. Discussion of the definition of categories. This is self-explanatory. Training here should include joint trips through the area to be studied, and comparison of results.

3. Instruction in the use of the observation form.

4. Discussion of randomization of times of observations.

5. Discussion of the objectives and end uses of the study.

A full discussion of all subject matter would be repetitious. The important thing to remember is that the director of the study, the observers, and management should all understand the part to be played by each. Since the observer's main contribution should be to gather accurate and reliable data, he should be trained primarily for this. The director is probably the most logical one to serve as instructor. In addition to the advantage of reducing the possibility of misunderstandings arising, this arrangement will allow the director to become acquainted with the observers, and them with him.

Training of observers should require no more than four or five hours at the outset. It should be scheduled as any other meeting, and there should be a clear indication that management considers the training to be important.

The Personnel Being Studied. Everyone to be studied should be told about the study. He should be asked to work normally, and should be promised that the results, in an abridged form, will be made public in the area. This abridgment should be carefully done from the personnel relations point of view. But all questions should be answered.

ANNOUNCING THE FACT THAT THE STUDY WILL BE TAKEN. In announcing the study to the personnel to be observed, good

personnel relations should be kept in mind. There should be no misunderstanding and suspicion arising from secret or surreptitious studies. This does not mean that the observer should be preceded by a brass band, but it does mean that each employee should feel that nothing is being "put over on him."

Some managements have made the mistake of shrouding in mystery efforts in work analysis or work measurement. *One has only to consider this attitude from the point of view of the observed employee to realize how unsound it is!* Work Sampling, when properly done, is an objective measuring technique of known reliability. If presented as such, there is every possibility of its effective use. It must be remembered that office and shop employees have in the past sometimes been the victims of poorly conceived and fundamentally unsound work measurement schemes. It is of the utmost importance that Work Sampling be introduced as it actually is, and not as what office or shop "grapevine" broadcasts it to be, in the absence of correct information.

It is desirable, therefore, that management should present its program in a logical, considered manner. There is no satisfactory alternative to this.

To summarize, the ultimate success of Work Sampling depends upon the extent to which preparatory steps have been "thought through," and upon the foresight of management and the director. Not all the preliminary steps are of equal importance. Personnel, tradition, and type of work situation make rigid rules hard to formulate. But there should be a clear statement of objectives, satisfactory measures of production should be established, personnel should be carefully selected, and the personal feelings of those to be observed should be considered. If the foundation is sound, the study will be easier to take, and will produce more satisfactory results. In this, Work Sampling is no different from other managerial activity.

5

Performing Work Sampling

In the performance of the data-gathering function in Work Sampling, there are several clear-cut steps to be followed. Keeping in mind the fact that each study will be different in some details, these steps are as follows:

Performing Work Sampling

1. Classifying into categories the activity to be studied
2. Designing the necessary forms
3. Developing properly randomized times of observation
4. Observing activity and recording data

The first three steps are joint activities among the director and the observers. The last is the responsibility of the observers.

Classifying into Categories the Activity to Be Studied. The mechanics of Work Sampling require that the observers gather data by observing the state or condition of the object or person being studied, classify this into one of several categories of activity, and record the observation by writing the designated number or letter which represents that category. Since the initial classification of activity governs the utility of the study, it follows that definition of categories should be done with care. A category may be defined as a group of similar activities or a specific type of activity which may be recognized by sight and may be considered homogeneous for purposes of

study. For example, in a department-store study, the category "customer service" consisted of "conversing with customer, showing merchandise at counter, or devoting full attention to a specific customer's needs while at counter." Note that the category *did not* include writing up a sale in the sales book, or moving to get stock. These were made the content of separate categories, for this particular study. For other studies, all might be combined. The detail is indicated by the objective of the study.

In general, the following rules should be observed in the classification of activity into categories:

1. Categories should be clearly and concisely defined, in writing. Examples will be given in the later chapters of the text. In the training of observers, drawing of inferences from results, and development of standards, such a set of written definitions is essential.

2. Categories should be capable of recognition by visual observation.

One of the advantages of Work Sampling is that those under observation need not be interrupted or disturbed in their work. An exception to this occurs in the event that detailed information, such as "items written," is required. In this case, the observer *first* makes the general categorization (such as "writing"), and then returns to the workplace to collect the more detailed information. This procedure is not necessary in most cases, but has been used successfully.

3. Categories must be chosen in the light of the objectives and end uses of the study.

Any particular type of activity which it is desirable to measure must first be separated from other activity. If it is desired, for example, to discover how much telephoning is done, it is necessary to have a separate category for telephoning. We cannot include talking on the telephone and talking with a

neighboring employee in the same category, because we could not then separate these at the conclusion of the study. Therefore, the objectives must be kept in mind; this is particularly true in the use of Work Sampling to help establish personal allowances and to determine personnel and machine utilization.

4. Categories should be selected to take advantage of already existing classifications of activity.

If there already exist in the work situation accepted and well-understood classes of activity (particularly if there are records to support them), it is wise to take advantage of these. For instance, we would certainly want to separate day work and incentive work, if these two types of work are part of the shop wage-payment plan. This might provide a check on the study, as well as on the existing system. Accounting codes, classification of labor, subcontracted work, and rework versus production work are other examples of existing classifications. Such existing designations should be considered in determining categories of activity.

There is no fixed optimum number of categories. For the initial study, perhaps no more than ten or twelve should be established. Limiting the number will not allow as great detail, but it has the following advantages:

1. The study will be easier to take.

2. Reliability will improve for each of the categories, since there will be relatively a greater number of observations per category.

As the study progresses, the number of categories may be changed. For example, it may be desirable to divide a category such as "operating machine" into the two separate categories of "production operation" and "rework operation." This must be done with care, so that the greatest possible number of observations may be carried forward. Generally,

though, after a few days of trial observations, the categories need some redefinition. At this point, they can be fairly well finalized and kept stable throughout the study.

To summarize, the following rules must be kept in mind in the selection of categories:

1. Establish the categories with care.
2. Define categories in writing, after discussion.
3. Visual recognition of each activity is necessary.
4. Do not lose sight of the over-all objective of the study.

DESIGNING THE NECESSARY FORMS. In the development of the forms to be used in recording observations, and in the analysis of data, the analyst should set an example in good form design; good practice should be observed in spacing, lettering, margins, and paper size. The procedure for collecting and interpreting data should be as simple as possible, and definitions and written instructions should be clear and concise. There is no need to belabor the point that "work simplification begins at home."

No inflexible systems of form exist, but in general, the following are required:

1. Written definitions of categories
2. Written procedure, including procedures for obtaining randomized times
3. Observation forms for recording original observations
4. Summary sheets for original data
5. Other graphic means of presenting data

These points are considered individually in the following paragraphs.

Written Definitions of Categories. These should be formulated at the time categories are selected. Definitions should be positive and clear. Exercise of observer's judgment should be minimized. Copies of these definitions should be distributed to observers, and elsewhere as necessary. As the study pro-

gresses, it may be necessary to change original categories. When this is done, all concerned must be given the revised definitions.

Written Procedures, Including Procedures for Obtaining Randomized Times. This should be a specific, step-by-step procedure for

Date ____________

Observer ____________

Activity Key

1. Operating and running
2. Operating and not running
3. Correcting
4. Summarizing
5. Testing
6. Available
7. Not available (maintenance)
8. Not available (CPC)

Machine	Activity ↘	Time Cycle of Observations Was Begun								Total
		9:	10:	11:	12:	1:	2:	3:	4:	
Key punch	1									
Key punch	2									
Key punch	3									
Key verifier	4									
Key verifier	5									
402 tabulator	6									
514 reproducer	7									
402 tabulator	8									
514 reproducer	9									
082 sorter	10									
082 sorter	11									
CPC	12									
412 [illegible]	13									

Fig. 5-1. IBM machine-time sampling sheet, general tabulating department.

the observers and others directly concerned with the study. It should be available for the initial training. The procedure for randomizing times (to be discussed later) should be included.

Observation Forms for Recording Original Observations. The particular objectives of the study, the degree of detail, the number of categories, and the number of men, machines, or conditions to be observed all govern the actual design of the

observation form. One type (Fig. 5-1) allows a full day's observations to be recorded on a single sheet. This requires that there be relatively few categories, the actual entry being a number designating the proper category. In another type (Fig. 5-2), categories are listed on one axis, and the subject of observation on another. A check mark is the actual entry, a

Analyst ______ Date ______ Dept. No. ______
Operator ______ Mach. Type ______

Time of observation																					
Condition / No. of observation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
I. Operating																					
1. Hand paced (on machine)																					
2. Machine paced																					
a. Operator idle																					
b. Operator gaging																					
c. Cleaning parts																					
d. Getting stock																					
3. Gaging parts																					
4. Handling stock																					
II. Delays																					
1. Talk with supervisor																					
2. Talk with fellow worker																					
3. Setup																					
4. Clean up machine																					

FIG. 5-2. Work Sampling data sheet.

separate sheet being necessary for each round of observations. In later discussion, various other examples will be shown.

The preceding types of forms will be used in a majority of cases. However, another more convenient method of recording observations is available to those companies which have the mechanical equipment necessary to process mark-sensed punched cards. Use of these cards greatly facilitates the processing of data, and its subsequent analysis. When these cards are used, it is necessary to reduce to numerical codes all the information pertinent to the study which must be recorded.

This is relatively a simple task. A sample of such an observation card, together with the numerical codes used, is shown in Fig. 5-3. In the processing of data, the use of mark-sensed cards and business machines offers a real advantage. However, only a relatively small number of installations exist, and Work Sampling alone probably would not justify rental of the necessary equipment. But if the equipment is already installed, it most certainly should be put to use.

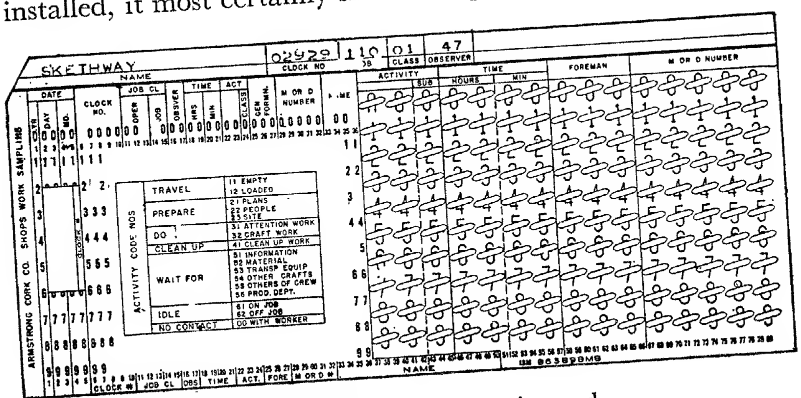


FIG. 5-3. Mark-sensed observation card.

Summary Sheets for Original Data. Summary sheets usually become necessary in a Work Sampling study in order to avoid handling an inordinate amount of paper. As is the case with any consolidation of data, the form should be designed to give a clear presentation of essential data, at the expense of detail. If the activity observed is cyclical, a form such as is shown in Fig. 5-4 makes for ease in calculating a moving average for plotting. If on the other hand all that is desired are cumulative dollars spent for each activity, a form such as Fig. 5-5 would be suitable. The summary forms may be set up to classify observations by the type of machine, type of personnel, area of the shop, or in any other way. One form may be used to summarize results in a particular shop or office, and another to consolidate these on a company-wide scale. It is in this

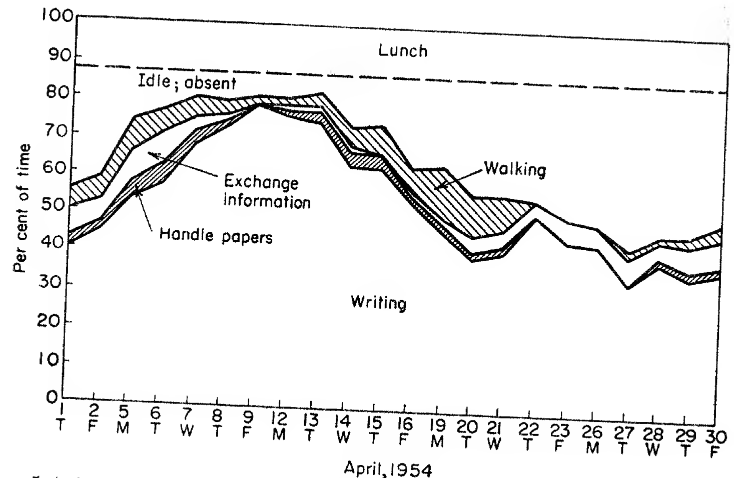


FIG. 5-4. Typical pattern of within-month cycle check posting clerks. Points, plotted cumulatively, are three-day moving averages, centered on the third day. Data from Work Sampling. Total observations: 4,068.

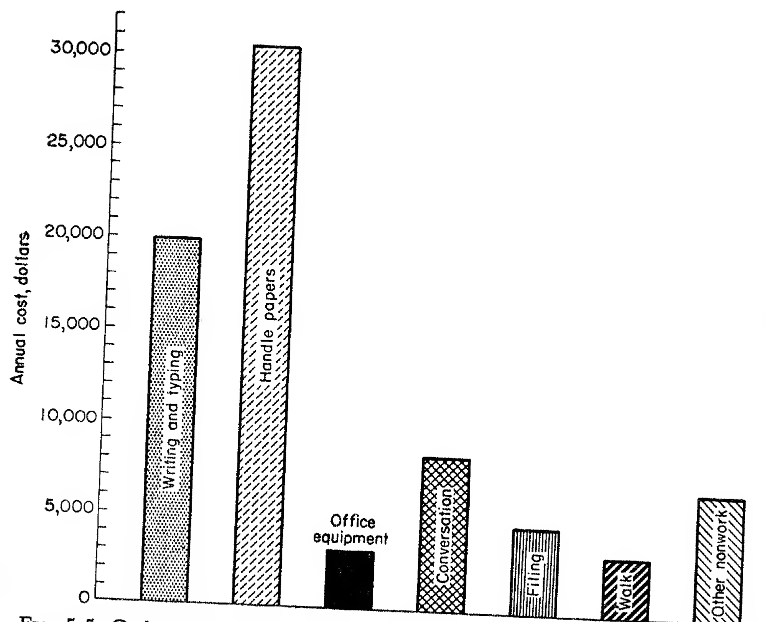


FIG. 5-5. Order and billing department Work Sampling summary in dollars.

summarization process, incidentally, that the advantages of mark-sensed cards and machine processing become most apparent.

Other Graphic Means of Presenting Results of Work Sampling. Into this classification of forms falls whatever charts or graphs the analyst cares to make in order to present to management the results of Work Sampling. These might take the form of running graphs of the most significant activity category, bar charts of total activity from office to office or shop to shop, or

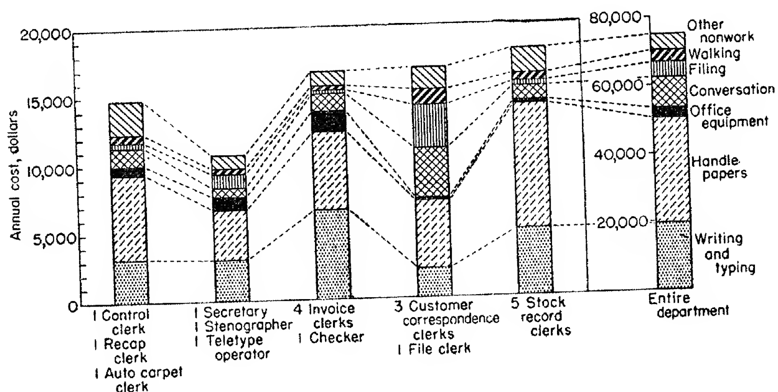


Fig. 5-6. Order and billing department Work Sampling summary.

many other standard graphic techniques. Figure 5-6 is an example of such graphic presentation.

Developing Properly Randomized Times of Observation. Randomness of observation times is essential. The end result of a Work Sampling study is a series of percentages of observations in each category of activity. The extent to which these percentages may differ from "actual" is determined by two basic sources of error. These are:

1. Systematic error
2. Random error

A systematic error may occur, for example, in the case of a machine which has a cycle which begins every hour on the

hour and the machine then operates continuously for 40 minutes. If Work Sampling observations always were taken at quarter past the hour, the machine would always be recorded as "operating." Similarly, if observations always were taken at quarter to the hour, the machine would always be recorded as "not operating." In both instances, a systematic error is induced by lack of randomization of observations. Similarly, in other situations if it became known that the observer always made his round of observations at, let us say, half past the hour, those being observed might make it a point to "be busy" at the time of observation. While in the latter case education and a proper introduction might minimize the error, it still is axiomatic that randomization of times is essential in all cases to reduce systematic errors in observations.

Random errors of observation, on the other hand, occur as a result of chance causes, and are inherent in any Work Sampling study. This type of error can be reduced almost to the vanishing point by taking a large number of observations. The chapters discussing statistics contain procedures appropriate for measuring this error. It is sufficient to state that these procedures are straightforward and well understood, and that this type of error is reduced as more observations are obtained.

The mechanics of developing randomness of times of observation are quite simple, but should be undertaken in the order presented. The steps in this procedure are as follows:

1. From the initial planning of areas to be studied, and the scope of time to be covered, define the time limits to be considered as the "whole" which will be sampled. This is particularly important when staggered shifts are the practice. It must be done in all cases.

2. Decide upon the number of observations per day (or

other period). Will eight observations per day be practical? Should the observer make rounds continuously? Or shall a decision be made to take 50 observations each week? Generally speaking, a round of observations on the average of once an hour should not be onerous for the observer. But here the director must use his judgment. If it is desired to accumulate information rapidly, and the physical area is small, 10 or 20 observations per day may be made. In some widely dispersed activities, taking observations entails much travel, and fewer observations are possible. A large number of observations is desirable, but the director must balance demands on the observers' time against the desire to acquire a large number of observations. Although no general rule can be established, it is common to have observers make eight rounds of observations a day.

J. C. Cooke, of the Engineering Department of E. I. du Pont de Nemours & Company, has developed a means of predicting the time required to make rounds of observations. This is explained in the following memorandum:

TO: J. M. KALBACH, JR.
FROM: J. C. COOKE
SUBJECT: ESD—CLERICAL MEASUREMENT—65021
WORK SAMPLING—TIME TO MAKE STUDY

We have developed a means of determining in advance the observer's work time in making a work sampling study. With this measurement we have been able to predict accurately the number of observers required for a particular study.

In a work sampling study it is usual to determine in advance the following:

(*a*) The number of observation locations
(*b*) The number of operators to be observed at each location
(*c*) The distance between observation locations
(*d*) The number of observations at each location per day.

With the above information the time to make an observation at a given location will be:

$.1 + .005D + .04N$

where: D = Distance in feet walked to observation point

N = Number of operators observed at the observation point

For example the daily observer time for a work sampling study could be calculated as follows:

Study Data

(*a*) Number of observation locations — 4

(*b*) Number of operators observed at each location

$N1 = 15$
$N2 = 10$
$N3 = 16$
$N4 = 9$

(*c*) Distance between observation locations:

$D1 = 60$ ft.
$D2 = 30$ ft.
$D3 = 50$ ft.
$D4 = 80$ ft.

(*d*) Number of daily observations at each location = 32

Normal Minutes of Observer's Time per Day

$32(.1 + .005 \times D1 + .04 \times N1) =$ 32.0 minutes
$32(.1 + .005 \times D2 + .04 \times N2) =$ 20.8 minutes
$32(.1 + .005 \times D3 + .04 \times N3) =$ 31.7 minutes
$32(.1 + .005 \times D4 + .04 \times N4) =$ 27.5 minutes
Total 112.0 minutes

This technique has been used to determine the number of observers required, and the demands made upon their time.

3. Within the limits previously established, select at random the times of observation. This can be done in accordance with instructions in Chap. 8.

4. Observing Activity and Recording Data. In observing the activity under study, and recording the results, the only general rule to follow is "Be careful." The observations form the source information of the study, and every effort must be made to avoid systematic error. While the procedure itself is quite simple, the observer should be careful to:

1. Make observations at the proper times
2. Avoid any biasing habit patterns in making observations
3. Explicitly, not attempt to anticipate any particular action, but rather to record what he sees at the given instant of observation

In a shop or office, for example, the observer might have to make his study in a large area. He should be careful *not* to follow the same route in each round of observations. This precaution helps avoid possible error in the event some employees resent the study, and "look busy" when the observation is made. As the observer takes visual notice of each person or machine, he should make proper notation of its state or condition at *that instant of time*. Depending on shop conditions it may be decided to use as the time of observation the instant the observer first sees each worker or machine, the instant the observer passes the machine or workplace, or some other definable time. But the observer should keep in mind the concept that Work Sampling may be likened to a series of photographs, and make his observations accordingly.

If the area to be covered is relatively small, and the activity may be recognized from the observer's desk, he may not have to leave his desk or normal work station. This is particularly true in some cases where the supervisor may act as the observer.

Make Observations at the Proper Times. The principle of randomization already has been discussed. In most cases, a logical method of ensuring randomness is to follow exactly the schedule of times for observation developed using tables of random numbers, chips, or some other device. At first, this will probably prove to be a burden, and will result in a little "clock watching." But after a short while most observers gain the knack of adhering to schedule. One observer used a wrist-watch alarm to remind himself of the time. Another

deactivated the loud bell of an alarm clock and stuck to his schedule using the clock.

If observations are not made on schedule, they still may be random. There are methods of testing this condition. In any event, the actual time of observation should be noted. It is better to make a round of observations late or early than to omit the round.

Avoid Any Biasing Habit Patterns in Making Observations. This caution applies not only to the route the observer follows, but also to any other habit, such as stopping at the same place each round for conversation or to check in, which might give undue advance notice of his observation. Or, if he passes a work station more than once, he may vary the part of the round at which he makes his observation.

Explicitly, Not Attempt to Anticipate Any Particular Action, but Rather to Record What He Sees at the Given Instant of Observation. In other words, the observer should not attempt to "second guess" the table of random times. If, for example, the machine observed is *now* operating, it should be so categorized, even though the observer knows that within a short time it will be idle. If enough observations are taken, the proportion of observations in each category will reflect the true proportion. Randomness of times of observation and the taking of large numbers of observations are the means of protecting the worth of the study. The observer should follow the rules; if he does, the results will be satisfactory. The observer should not impose his own opinion on the results, but should concentrate on gathering basic data of the greatest reliability.

In addition to the above precautions, there exist many special circumstances in the making of observations. For example, in certain cases it may be considered necessary to obtain more detailed information than it is possible to gain by a quick glance. In such cases, the general category of activity may

be established by a first observation; the observer may then go to the workplace under study and obtain the more detailed information. An example of this occurred in a study made of drafting activity. The observer (who was a supervisor) made his observation and classified individual activities into general categories such as "drawing," "checking blueprints," etc. The observer then walked around to the individual workplaces and inquired as to the specific nature of the work, that is, which projects and what type of print was being worked on. The observer then completed his recording of the observation.

This method of dividing the round of observations into two parts was most satisfactory in the particular case mentioned. The draftsmen knew that their activity had been classified into general categories; that is, the basic type of activity had already been recorded. All that was left for the observer to do as he visited each workplace was to identify the specific type of print or problem on which the man was working. Therefore, there was no resentment, and in fact, both the observer and the draftsmen volunteered the opinion that the study was of great benefit because it provided a natural means of instituting discussion of the work. Previously, the draftsmen had hesitated to "bother" the supervisor with small problems, and the supervisor had felt that he did not want to seem to be "checking up" on performance.

This same technique of establishing the general category on an initial observation, then following with a more detailed observation, also may be useful in the office. The basis for following this procedure is that it is not necessary to question each employee; only certain categories are involved. Also, there will be no urgency to move along to complete the round of observations, and a better personal relationship should result. Finally, the study should be less subject to error arising from the giving of advance notice of observation.

Another question which sometimes arises is whether or not it is advisable to combine the time-study technique of rating (or leveling) with the technique of Work Sampling. By "rating" or "leveling" is meant the relating of an observed performance to some sort of "standard" of performance. As the liberal use of quotation marks indicates, this is a subject of some controversy in the practice of time study. Rating has become an integral part of most methods of time study, however, and is widely practiced. As an example, a man being studied might be rated at 120 per cent effectiveness, and the observed time multiplied by 1.20 to arrive at the time allowed for the work unit. The basis for this adjustment would be that the observed performance exceeded the standard expectable performance by 20 per cent of effort, pace, or whatever similar expression of standard existed in the plant. The purpose of the introduction of this adjustment is to allow for differences in operator performance in the setting of a consistent group of time standards.

A discussion of the merits and levels of reliability of rating is beyond the scope of this book. It is sufficient to say that the practice is quite widespread, and undoubtedly will exist in certain work situations where it may be desired to institute Work Sampling as a supplementary technique to time study. Gomberg* and Mundel† have written excellent critiques of time-study rating. The reader is encouraged to refer to these works.

There are two significant features of rating, however, which must be considered in combining the technique with Work Sampling. These are:

* W. Gomberg, "A Trade Union Analysis of Time Study," Science Research Associates, Chicago, 1948.

† M. E. Mundel, "Motion and Time Study Principles and Practice," 2d ed., Prentice-Hall, Inc., Englewood Cliffs, N.J., 1955.

1. Rating is subject to error. The acceptable limit of this error usually is fixed at plus or minus 10 per cent for 90 per cent of the ratings made.

2. Almost all rating procedures require careful description of the nature of the job and of its surrounding difficulty.

Keeping these two features in mind, the conclusion may be reached that errors of rating and the normal errors of Work Sampling will be hard to separate and analyze if rating is done during observation. At the very least, an unknown will be introduced, and at worst, all the ills which may have accrued to a time-study system will be carried over to Work Sampling. Furthermore, since rating is an activity which requires time, the feature of ease of observation which normally is associated with Work Sampling will be lost. The authors, therefore, do not recommend that rating be done as part of a Work Sampling study.

If it is desired to perform time-study rating while making the observations in Work Sampling, be careful to maintain the original proportions observed in the study, and to avoid adjusting that proportion of observations in the "working" categories. In other words, rating may be used in whatever way seems consistent with the existing time-study plan, but the basic data should be available, and should be used in the original concept of proportions of the number of observations. The mathematics of Work Sampling are not designed to include percentage adjustments based on subjective judgments by the observer. If management feels that such ratings might help in some type of appraisal of shop activity, they may be included. But this should be done with caution, and with the knowledge that there is being imposed on the Work Sampling study an additional technique for which Work Sampling was not designed.

There are, however, certain circumstances in which per-

formance rating may be done in conjunction with Work Sampling. These are:

1. There exists in the shop a highly complex product mix.
2. Well-trained observers are available, that is, men who are capable of consistent and accurate rating.
3. The principle of rating is acceptable to employees.

Under these conditions, Work Sampling and rating may be combined. However, certain of the advantages of Work Sampling are thereby lost. Barnes* describes the technique he suggests using in such situations.

* Ralph M. Barnes and Robert B. Andrews, "Performance Sampling in Work Measurement," *The Journal of Industrial Engineering*, vol. VI, no. 6, November–December, 1955.

6

Sampling and the Law of Averages

Statistics—the Science of Distribution

Statistics has been defined by Wiener* and others as "the science of distribution." By "distribution" is meant the behavior of data phenomena according to repeatable patterns. The use of statistics, that is, the group of mathematical and philosophical tools collectively known as "statistics," requires that the practitioner be keenly aware that it provides only *tools* of analysis: *means, not ends.* The historical development of these tools, until recently, has been almost entirely in the medical, biological, and agricultural research areas, and unfortunately much of the literature of instruction is slanted almost exclusively in these fields.

In the past thirty years, the extremely rapid growth of the statistical quality control field in industrial engineering has done much to open areas to statistics which had hitherto been closed. Minds trained in engineering have been exposed, in many companies, to the advantages of some of these statistical tools. The future of industrial engineering seems unquestionably to involve a tremendous expansion in the use and appreciation of these statistical tools. For this reason, much that follows is intended to lay a foundation for sampling in many other ways than Work Sampling, because the whole kit of

* Norbert Wiener, "The Human Use of Human Beings," Doubleday & Company, Inc., New York, 1954.

tools is equally useful in other types of industrial engineering analysis.

The Law of Averages

In all sampling, for whatever purpose, there is always a conviction on the part of the sampler that the result of the sample will be a useful measurement of the characteristic desired. But as we have seen, the result must be considered as only an *approximation* of a true measurement. In the back of his mind, the sampler is convinced, or should be, that he will minimize the danger of error in the result by careful selection, precise measurement, and correct interpretation. In the vernacular, the law of averages should protect him.

Intuitive grasp of this law of averages is very common. It simply implies that the entire mass of items or data, if we had it, would produce measurements little different from our sample, because *extreme values would tend to cancel each other out!*

Statisticians express this law of averages as two separate phenomena:

1. The law of large numbers
2. The normal curve of error

The Law of Large Numbers

The law of large numbers, simply put, states that if samples are drawn at random from an unchanging mass of items, successive samples will distribute themselves according to an approximately repeatable pattern. This idea hinges upon two basic assumptions:

1. Everything varies. No two items are exactly alike, were it possible to measure with a fine enough instrument.
2. Groups of items from the same mass will show essentially the same distribution when we plot frequency of occurrence against measurement.

Here we have the concept of the "frequency distribution of measurements." A frequency distribution is nothing more than an expression of this pattern of measurements, and is usually a graphic portrayal. This concept changes somewhat when we deal with the "yes-or-no" type of data, called "attributes." For example, in testing light bulbs, we may find that *either they light or they do not;* this is an "attribute" test, because it consigns results to only two categories.

Let us pause here and examine closely this "yes-or-no" type of measurement, as opposed to the more finely measurable one, such as our cans of tomatoes.

Testing of light bulbs could be carried out by measuring the candlepower of light, to an extremely fine distinction if we wished. One such measurement would be zero, where we find *no* light being emitted. If we assign *groups* of foot-candle measurements to a single value, for example, 0.01 to 0.10 foot-candle as one group, 0.11 to 0.20 as another, etc., we are actually compromising the degree of measurement precision which is possible. This is quite logical, since everything varies and we may have no need for precision greater than 0.1.

Note that we have taken light bulbs which are all different from each other in their ability to emit light, and have grouped approximately similar bulbs together. In so doing we have set up discrete categories (that is, mutually exclusive groupings, each group containing different values which will be considered as the same value!) for purposes of measurement. We have therefore changed what is really a *continuous* distribution into a *discrete* one.*

When we draw a sample of 1,000 light bulbs and arrange the values obtained into such a discrete frequency distribution,

* Perhaps the idea of a "continuous" distribution can be grasped better by use of time as a variable. While *time* is really divisible into infinitely small graduations, we break it up for analysis into seconds, minutes, hours, etc., neglecting smaller differences, and create *discrete* distributions.

draw another sample of 1,000 and arrange it, and another, and another, etc., the law of large numbers simply tells us that if we are drawing our successive samples randomly from the same unchanging mass of light bulbs throughout our sampling, we will find these successive distributions to be essentially alike, although not necessarily *exactly* alike.

It can be seen quite readily that what we are doing in the "yes-or-no" type of sample measurement is really setting up very gross sizes of categories! Again, under the same condition, we shall find essentially the same distribution, except that now we shall have only two categories. Again, the law of large numbers applies equally well!

Let us take an example to illustrate these concepts of discrete versus continuous data, and attributes versus measurements (sometimes called "variables"). Suppose that we take 5 samples of 1,000 light bulbs from a mass containing 1,000,000 bulbs and perform a "go-not-go" test. Our categories are two:

1. A bulb emits light.
2. A bulb does not emit light.

In the 5 samples, we might find the results given in Table 6-1. If we take these same 5 samples of 1,000 each, and meas-

TABLE 6-1

Sample No.	Good	Defective	% Defective
1	980	20	2.0
2	987	13	1.3
3	985	15	1.5
4	990	10	1.0
5	988	12	1.2
Total........	4,930	70	1.4 (average)

ure the quantity of light emitted, in foot-candles, according to the needs of our results, we may find distributions such as those

in Table 6-2. This table reflects test results on exactly the same samples as the attributes test, except that we have used "measurement" categories here that are more finely drawn than were the "attributes" categories. Both finer and grosser

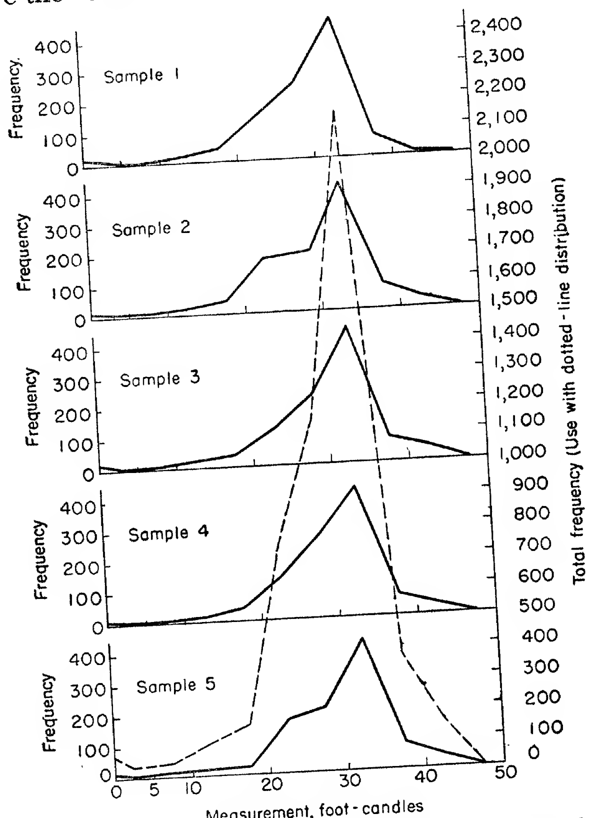


FIG. 6-1. Frequency distribution of values in Table 6-2.

categories are available to classify these same data. With ability and desire to measure to infinitely fine graduations, we would have a continuous distribution. The discrete distribution has been demonstrated, as has the grossest form of discrete categorization, which we call the "attributes" distribution, usually expressed as a proportion in each of two categories.

TABLE 6-2

Sample No.	Cell Interval										
	0	0.1 to 5.0	5.1 to 10.0	10.1 to 15.0	15.1 to 20.0	20.1 to 25.0	25.1 to 30.0	30.1 to 35.0	35.1 to 40.0	40.1 to 45.0	Σ
1	20	5	0	21	36	143	246	454	65	10	1,000
2	13	8	10	20	43	180	199	414	82	31	1,000
3	15	6	12	25	39	120	221	441	76	45	1,000
4	10	8	6	17	42	135	264	417	69	32	1,000
5	12	5	18	22	23	173	207	424	78	38	1,000
Σ	70	32	46	105	183	751	1,137	2,150	370	156	5,000

The law of large numbers has been reflected in both the "attributes" and "measurements" classifications. Within each series of sample values, we see approximately similar shapes of distribution in comparing the five samples.

The Normal Curve of Error

The normal curve of error, which is the other type of form which the law of averages assumes, refers to the shape of a well-known frequency distribution to which nearly all of us have been exposed at one time or another. Its derivation* is not important here, but its application and use are very worthy of exploration.

During the development of much of the science of statistics, experimenters and researchers have found many natural phenomena which appear to distribute themselves according to a law of large numbers pattern which is *symmetrical* around a *single* peak, or mode.† This common distribution curve is

* For an excellent and mathematically simple derivation, see I. W. Burr, "Engineering Statistics and Quality Control," McGraw-Hill Book Company, Inc., New York, 1953.

† A "mode" is that value in a frequency distribution which occurs *most frequently*.

further characterized by having its average, or mean, value equal exactly to its mode, and to its median.*

Experimental data in a large number of analyses led to the derivation of the normal or Gaussian curve, which fairly well describes the statistical measurements of many distributions which occur in nature. The normal curve has been a great aid in the growth of our knowledge of the science of distributions. The normal curve establishes precise measurements

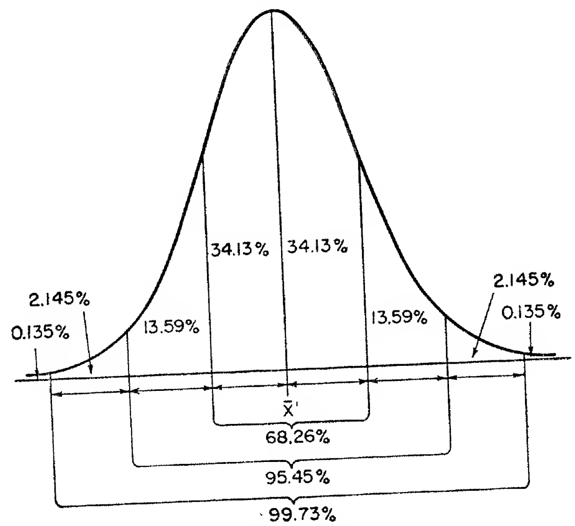


FIG. 6-2. The normal curve.

for the proportion of sample values which lie between any value and the center or mean, or between any two values along the range of possible values occurring in measuring.

By inspection of the normal curve picture (above) it can be seen that the two "tails" of the distribution do not touch the axis, or line, along which the values are located. *In theory, the curve extends in both directions indefinitely, never touching.*† Fur-

* A "median" is the center, or middle value, if all items in the distribution are "arrayed" from low to high.

† The normal curve is thus said to be "asymptotic to zero," extending from $-\infty$ to $+\infty$.

thermore, the normal curve is a continuous function, and not a grouped or discrete one.

The normal curve is known *completely* as to its mathematical characteristics, and in this respect it stands virtually alone as a statistical distribution function.

Unfortunately for the normal curve concept, however, it is a little *too* well known! Its simplicity, its measurements, and its general characteristics are frequently assumed to apply to distributions which are not really even close approximations to it. It has been the experience of the authors that the occurrence of the normal curve distribution is quite rare in most man-made phenomena such as those usually encountered in industrial engineering work.*

The normal curve is extremely useful, however, not as a representative shape for a distribution of individual values, but in its behavior as an expression of the law of averages. In this capacity, it is usually referred to as the "normal curve of error," for it describes the distribution of *average* values from successive samples, drawn randomly from the same unchanging mass of data.

The Control Chart principles set out by Shewhart,† and others, rest for their interpretation and use on this remarkable ability of the averages and ranges of successive samples, drawn randomly from the same unchanging mass of data, to distribute themselves approximately "normally." We shall have occasion (in a later chapter) to pursue this idea further.

Let us take an example now and see how this normal curve of error operates. Returning to our Work Sampling technique, we might find that a gross, or attributes, breakdown of

* The most common distribution shape seems to be the unsymmetrical, unimodal, skewed shape, having a blocked, or zero, measurement at the modal end of the measurement scale.

† W. A. Shewhart, "Economic Control of Manufactured Product," D. Van Nostrand Company, Inc., Princeton, N.J., 1931.

categories into, say, Writing and Other, would yield the results shown in Table 6-3, being 50 successive rounds, or cycles, of observations of 30 people. After 50 cycles, a frequency distribution of the number of observations of Write per cycle would appear as in Fig. 6-3. The average number of observations of Write per cycle was 9.84, or 32.8 per cent, in

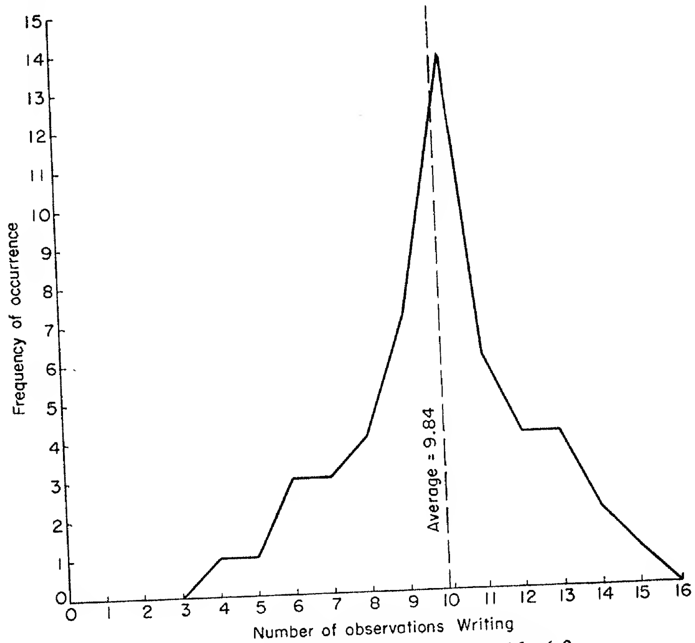


FIG. 6-3. Frequency distribution of Table 6-3.

the sample of 30. The most frequently occurring number was 10, or 33.3 per cent, while the median value is also 10, indicating a very striking similarity to the normal curve in the mean, median, and mode. There is a single mode, and a close symmetry, also found in the normal curve.

One more characteristic of the normal curve must be examined, however, before proceeding. The mean, median, and mode are all measures of *central tendency*, i.e., the centroid, of the distribution; some measure of the *dispersion* of the indi-

TABLE 6-3

Cycle No.	No. of Observations Recorded as Write	No. of Observations Recorded as Other	Cycle No.	No. of Observations Recorded as Write	No. of Observations Recorded as Other
1	8	22	26	10	20
2	11	19	27	12	18
3	10	20	28	10	20
4	6	24	29	9	21
5	13	17	30	12	18
6	11	19	31	10	20
7	7	23	32	5	25
8	10	20	33	7	23
9	9	21	34	10	20
10	14	16	35	13	17
11	4	26	36	10	20
12	10	20	37	8	22
13	8	22	38	15	15
14	10	20	39	10	20
15	11	19	40	9	21
16	10	20	41	10	20
17	12	18	42	8	22
18	13	17	43	13	17
19	9	21	44	9	21
20	6	24	45	12	18
21	11	19	46	9	21
22	7	23	47	6	24
23	11	19	48	11	19
24	14	16	49	10	20
25	9	21	50	10	20

viduals around the mean-median-modal value must be made, since the normal curve demands a certain "spread" of items around a center value.

Several measures of dispersion are described in textbooks in statistics, but the measure which is in widest use, and is most efficient, is the *standard deviation*, or root-mean-square deviation, usually symbolized by the lower-case Greek letter sigma, or σ. This measure is derived by finding how far each item in the distribution departs from the mean value, and then squaring this deviation; these squared deviations are sum-

mated, then divided by the number of items, and, finally, the square root is extracted. The value obtained by summating these squared deviations and dividing by the number of items is called the "variance," usually called s^2 or σ^2, and the square root of the variance, s or σ, is the standard deviation.

The standard deviation of the normal curve, when laid off on either or both sides of the mean, encloses known portions of the "area" under the curve bounded by any two values expressed in standard deviations, plus or minus in respect to the mean. These areas are direct expressions of the proportions of items in any normal distribution which should be found between these points. Shown as Appendix 3 is a Table of Areas under the Normal Curve, where these areas are expressed as between two points measured in standard deviations above or below the mean.

Statisticians are accustomed, in this country, to using even numbers of sigmas as quick reference points for testing any observed distribution for normality. In the normal curve, the area enclosed between $+1\sigma$ and -1σ is 68.26 per cent; between $+2\sigma$ and -2σ lies 95.45 per cent, and between $+3\sigma$ and -3σ lies 99.73 per cent. Additional increments in σ add very little to this area. The standard deviation computation for our 50 sample values is shown in Table 6-4.

While this simple comparison shows a strong tendency of the observed data to be "normal" in so far as spread, or dispersion, is concerned, more powerful tests are shown in any standard text in statistics, to determine whether a distribution is really "normal." From these 50 samples of 30 each, we have arranged the averages of samples into a distribution which is approximately normal. Shewhart demonstrated this normal curve shape in the distribution of averages of samples from very nonnormal masses of data. Even from triangular and rectangular distributions of individual items, when samples are

TABLE 6-4

X Value	f No. of Items	fX	d	d^2	fd^2
4	1	4	−5.84	34.1056	34.1056
5	1	5	−4.84	23.4256	23.4256
6	3	18	−3.84	14.7456	44.2368
7	3	21	−2.84	8.0656	24.1968
8	4	32	−1.84	3.3856	13.5424
9	7	63	−0.84	0.7056	4.9392
10	14	140	+0.16	0.0256	0.3584
11	6	66	+1.16	1.3456	8.0736
12	4	48	+2.16	4.6656	18.6624
13	4	52	+3.16	9.9856	39.9424
14	2	28	+4.16	17.3056	34.6112
15	1	15	+5.16	26.6256	26.6256
	50	492			272.7200

$N = 50 \qquad \Sigma = 492$

$$\text{Mean} = \bar{X} = \frac{492}{50} = 9.84$$

$$\text{Standard deviation} = \sqrt{\frac{\Sigma fd^2}{N}} = \frac{\sqrt{\Sigma fd^2}}{\sqrt{N}}\ \sqrt{\frac{272.72}{50}} = \sqrt{5.4544}$$

$$= 2.335$$

$\bar{X} \pm 1\sigma = 9.84 \pm 2.335 = 7.505$ to 12.175, or 8 to 12
$\bar{X} \pm 2\sigma = 9.84 \pm 2(2.335) = 5.170$ to 14.510, or 6 to 14
$\bar{X} \pm 3\sigma = 9.84 \pm 3(2.335) = 2.835$ to 16.845, or 3 to 16

	Per Cent of Area between	
	Normal Curve	Observed Distribution
$\bar{X} \pm 1\sigma$	68.26	70.00
$\bar{X} \pm 2\sigma$	95.45	94.00
$\bar{X} \pm 3\sigma$	99.73	100.00

drawn randomly from an unchanging mass, the *averages* of these samples will themselves be a normal curve, enabling us to use the normal curve statistics to advantage, regardless of the shape of the particular distribution from which the samples are drawn.

The normal curve of error, then, shows us that so long as the sample values are drawn randomly *and the mass of individuals remains unchanged*, extreme fluctuations caused by the vagaries of sampling will tend to *cancel each other out*. Thus the law of averages holds.

It would follow as a corollary, however, that if (1) samples are *not* drawn randomly, and/or (2) the composition of the mass *changes*, during sampling, that the distribution of sample averages will *not* be normal, and, of course, extreme values will *not* cancel each other out, and the law of averages will *not* be true!

Using the Normal Curve of Error in Work Sampling

The principal use of the normal curve in Work Sampling, as in Control Charting, lies in its value as a method for defining the limits within which successive sample proportions drawn from the same distribution should fall, using a probability level chosen by the user.

In the next chapter, we shall examine another basic mathematical tool which utilizes the normal curve concepts in its application.

7

The Binomial Theorem— Basic Analysis Tool in Work Sampling

Introduction

In order to use Work Sampling properly and to draw inferences from samples correctly, it is necessary to have some knowledge of "probability theory." Many texts and courses are available in this field of study. This chapter will attempt to distill much of this theory which applies to Work Sampling.

The Additive Nature of Probability

In the simplest type of estimation or prediction situation in which probability theory is used, such as in the prediction of the outcome of a flip of a coin, the various ways in which the event can happen are known in advance. The tossing of a coin may result, for instance, in one of three things happening:

1. The coin may come to rest head up, tail down.
2. The coin may come to rest tail up, head down.
3. The coin may come to rest on edge, neither face up.

The fact that no other result may happen leads to the statement that we have defined all the ways in which the event may take place, and we define the summation of the three ways as certainty, i.e., we are certain that one of these three events will happen.

This total probability is always defined as unity, or 1.000.

The probability that either event 1, 2, or 3 will happen is expressed as a proportion of unity, or something less than 1.000 . . . , and is usually expressed as a decimal amount, e.g., 0.50, or as a fraction, 1/4 or 1/2, etc. The summation of these individual probabilities is unity, or 1.000.

In our coin flipping, for example, we may have probabilities of each of the three events expressed as, say, 0.4999, 0.4999, and 0.0002, totaling 1.000.

In a bridge game, the probability of being dealt any one card may be considered as one in fifty-two, assuming a thorough shuffle and straight deal. Thus the probability of drawing an ace of spades is 1/52, or 0.01923077, etc. The probability is the same for each other card.

In Work Sampling, the probability of occurrence of each category can be expressed as a fraction or proportion, these amounts totaling 1.000. In the example used in Chap. 6, the probability of observing an individual person Writing is apparently about 9.84/30, or 32.8 per cent, or 0.328; of the Other category, therefore, 0.672; these two totaling 1.000.

The Compounding Nature of Probability

If the probability of one event (*a*) is 1/2, or 0.50, and of another (*b*) is also 1/2, 0.50, and there is no other way in which the event may happen, the probability of event *a* occurring twice in succession under conditions where the probabilities remain constant, and the events occur under conditions of random sampling, is $1/2 \times 1/2$, or 0.50×0.50, or 1/4, or 0.25. Similarly, the probability of the same event on three successive occurrences is $1/2 \times 1/2 \times 1/2$, or 1/8. In other words, the probability of one result occurring n times in succession is its probability raised to the nth power. Let us take some examples of this multiplicative or compounding effect,

where probabilities remain constant, and random choices are maintained.

In a coin-tossing experiment, assuming the probability of a head or a tail each equal to 1/2 (i.e., ignoring the possibility of its coming to rest on its edge), the probability of tossing a head on each of three successive tosses is $1/2 \times 1/2 \times 1/2$, or 1/8. The probability of *any other combination of heads and tails totals, therefore,* 7/8. The eight ways in which the coin may land on three successive tosses are:

H	H	H
H	H	T
H	T	H
T	H	H
T	T	H
T	T	T
T	H	T
H	T	T

Combination	Occurrences
3H	1
2H, 1T	3
1H, 2T	3
3T	1
Total	8

Thus it can be seen that three heads should occur only once in eight sets of three tosses, *in the long run.*

In our Work Sampling example, if the best estimate we have available of the proportion of time spent in Writing is 0.328, or 32.8 per cent, then the probability of observing the same person Writing on five successive random observations is 0.328^5 or $0.328 \times 0.328 \times 0.328 \times 0.328 \times 0.328$, or 0.003796. More properly stated, the probability of such a series of five consecutive observations is 0.3796 per cent, *in the long run, given a large number of such series of five consecutive random samples.*

This insistence on "the long run" as the proper basis for the consideration of true probabilities is made necessary because of random, or chance, influences exerted on any small sample. Perhaps this is easy to grasp intuitively since on each eight sets of three tosses of a coin we would hardly expect to see exactly the results shown above *each time!* However, as the number of samples of three tosses increased to 80, or 800, or 8,000, we

would expect to see a closer adherence to the ratio of 1:3:3:1. For a relatively small number of samples, we could have considerable deviation from this.

To illustrate further this same idea, if we tossed the same unbiased coin *twice*, we would not be surprised if we got two heads or two tails, even though we know that the coin should land with a head or a tail up with equal frequency *in the long run.*

The Binomial Theorem

Mathematicians have supplied us with a very simple way to express these long-run probabilities where an event may happen in one of two ways. In order to explore the binomial theorem we must adopt some shorthand notations first:

Let p = the probability of result A

Let q = the probability of result B

Let n = the number of sample items drawn

Assume: A and B are the only ways in which the event can occur, and are mutually exclusive; i.e., if A happens, B cannot, and vice versa.

Assume: Random sampling conditions prevail, with no change in p and q throughout the sampling process.

Therefore

$$p + q = 1.000 \qquad \text{and} \qquad (p + q)^1 = 1.000$$

The binomial theorem is

$$(p + q)^n = 1.000$$

This equation can be expanded by the use of simple algebra.

If $n = 2$, then

$$(p + q)^2 = p^2 + 2pq + q^2 = 1.000 \tag{1}$$

If $n = 3$, then

$$(p + q)^3 = p^3 + 3p^2q + 3pq^2 + q^3 = 1.000 \tag{2}$$

If $n = 4$, then

$$(p + q)^4 = p^4 + 4p^3q + 6p^2q^2 + 4pq^3 + q^4 = 1.000 \qquad (3)$$

Now let us assume this is the coin-tossing experiment developed previously in this chapter. Now $p = 0.50$ and $q = 0.50$, being the respective probabilities of heads and tails. "Plugging in" these values of p and q in formulas (1) to (3), above, yields

$$\begin{aligned} 0.5^2 + 2(0.5)(0.5) + 0.5^2 &= 1.000 \\ 0.25 + 0.50 + 0.25 &= 1.000 \end{aligned} \qquad (1)$$

$$\begin{aligned} 0.5^3 + 3(0.5)^2(0.5) + 3(0.5)(0.5)^2 + 0.5^3 &= 1.000 \\ 0.125 + 0.375 + 0.375 + 0.125 &= 1.000 \end{aligned} \qquad (2)$$

$$\begin{aligned} 0.5^4 + 4(0.5)^3(0.5) + 6(0.5)^2(0.5)^2 + 4(0.5)(0.5)^3 + 0.5^4 &\\ = 1.000 &\\ 0.0625 + 0.2500 + 0.3750 + 0.2500 + 0.0625 &\\ = 1.000 & \end{aligned} \qquad (3)$$

In formula (1), the probability of two consecutive heads, or two consecutive tails, is 0.25, or one in four, and of one head and one tail is 0.50, or one in two. By the same interpretation in formula (2), the probability of three consecutive heads, or tails, is 0.125, or one in eight, of two heads and one tail is three in eight, etc. In formula (3), the probability of four consecutive heads is 0.0625, or one in sixteen, etc.

The examples above show the perfect symmetry which exists in the binomial formula expansion when $p = q = 0.50$. In fact, the binomial expansion in the case where $p=q=0.50$, and *n becomes extremely large*, is virtually identical to the *normal curve*, except that it has finite limits, rather than infinite ones as in the normal curve. This property of the binomial makes the normal curve an excellent approximation of it, and an extremely useful Control Chart aid, when only two probabilities are involved, and p and q both lie close to 0.50.

However, the binomial expansion is most useful as a probability expression in its own right, for seldom does the equiva-

lent condition of p and q prevail! Normally, we must be prepared in Work Sampling for *any* probability from 0.001 to 0.999, and we shall usually have many more than two categories! The binomial expansion enables us to handle both conditions.

To take care of the limitation to two categories, A and B, having probabilities of p and q, respectively, we need only take any one category as A, and consider the *summation of all other categories as* B, and we can fit our problem to the binomial under this method,

$$q = 1 - p$$

and we can consider the binomial expression as

$$[p + (1 - p)]^n = 1.000$$

To take care of the full range of values which p may have, we can simply use any value of p in our expression, above.

In a Work Sampling example, suppose Writing has been found to be 20 per cent of total observations, over past studies. What is the distribution of Writing versus Other categories which we should expect in a large number of samples of five observations?

To solve this,

$$[p + (1 - p)]^n = 1.000$$

becomes

$$[0.2 + (1.0 - 0.2)]^5 = 1.000$$

$$0.2^5 + 5(0.2)^4(0.8) + 10(0.2)^3(0.8)^2 + 10(0.2)^2(0.8)^3 + 5(0.2)(0.8)^4 + 0.8^5 = 1.00000 \quad (4)$$

$$0.00032 + 0.00640 + 0.05120 + 0.20480 + 0.40960 + 0.32768 = 1.00000$$

Thus the distribution (long run) which we should expect in samples of five random observations of such a work situation as this, where the true proportion of time spent in Writing is 20 per cent, would be:

5 Writing, all Others	none	=	00.032%
4 Writing, all Others	1	=	00.640%
3 Writing, all Others	2	=	05.120%
2 Writing, all Others	3	=	20.480%
1 Writing, all Others	4	=	40.960%
None Writing, all Others	5	=	32.768%
	Total	=	100.000%

Similarly, the same type of expansion could be made for any combination of p, q, and n. However, as p and q become more precise, and as n increases, this calculation becomes fiendishly laborious. Fortunately, short-cut aids are readily available to assist us in working these out, provided n does not exceed 100.†

Before going on to the further use of these concepts, it is well to note that such questions as the following can now be answered for the above distribution:

1. What is the probability of drawing, in a sample of 5, 3 or more observations in the Writing category? This can be found by adding the probabilities of obtaining 3, 4, and 5 in a sample of 5, or 5.792 per cent.

2. What is the probability of obtaining not more than 2 observations nor less than 1 observation in the sample of 5, in the Writing category? This is found by adding the probabilities of finding exactly 2 and exactly 1, or 61.440 per cent.

Incidentally, the reader may be acquainted with the so-called "Poisson distribution," described and referred to in books on quality control and acceptance sampling. Very simply stated, the Poisson distribution is an approximation of the binomial when p (or q) becomes very small (i.e., in the neighborhood of 5 per cent or less) and n becomes large (i.e., 100 or more). The user of Work Sampling will have little if any need of the Poisson distribution, since the binomial dis-

† National Bureau of Standards, U.S. Department of Commerce, "Tables of the Binomial Probability Distribution," AMSG, Government Printing Office, 1952; H. G. Romig, "50–100 Binomial Tables," John Wiley & Sons, Inc., New York, 1947.

tribution covers adequately the full range of values of p and q, and offers easy, accessible computation short cuts.

The Use of Confidence Limits

In our daily practice of sampling, we frequently find need to set up some limits within which we expect results to fall. To take an example, if you and a friend are betting on the flip of a coin, and he wins the first toss by betting on a head, you might reason that since the coin has no "memory," the probability of a tail on the second toss is still one-half, only to see the coin fall heads up again. And so the same logic might lead to a third loss, and a fourth, through successive heads. But would you permit the fifth, sixth, etc., toss to continue to fall heads? How about the tenth? Suppose it went 15 times, each time a head? Would you still bet 50–50, on the premise that the coin "has no memory"?

That there is a very common fallacy in the thinking of many people in this matter can be verified by anybody who has attempted to teach statistics. Sooner or later in such a situation, each person reaches his own "limit of credibility" or "limit of confidence" in the lack of "memory" he assumed was present in the coin! For some, three or four straight heads (or tails) are enough to cause them to call a halt to the proceedings in order to examine the coin. For others, as many as seven or eight will suffice, and a stubborn few, locked in the vise of a mental assumption they do not realize they possess, will go on betting 50–50. (These last are "suckers," and good prey for "con" men!)

What is the paradox here? The answer is amazingly simple. To tosses of a coin, most people bring the assumption that the coin is unbiased, that is, has an equal probability of falling on one side or the other, and hence consider "even money" a fair statement of the odds. Therefore, they assume,

from an intuitive basis, that the number of heads and of tails should come out even over an extended series of tosses, so that whether one bets heads *or* tails on any given single toss is not important. In other words, the law of averages will protect them! This law of averages protection rests on the two hypotheses of *true lack of bias in the coin* and *true randomness in the tossing!* The facts in the case sometimes show that one or both of these hypotheses may be incorrect. It is a demonstrable fact that no two coins are balanced exactly alike and that no one coin is *perfectly* balanced.* Furthermore, many series of tosses are performed under distinctly *nonrandom* conditions!

The logical impasse faced by the bettor when five or six straight heads appear can be resolved easily if he will but reexamine his assumptions! While in the case of coin tossing, the approach to balance is very close, and nearly random conditions may usually apply, this is seldom true when sampling where no convenient p or q is available.

In most industrial or business sampling situations, assumptions similar to these, taken at the outset, may lead to devastating results. The user of Work Sampling will do well to avoid making assumptions concerning bias or randomness.

In the coin-tossing case, the fact that there is a personal limit of confidence for each of us, in the number of consecutive tosses of the same face which he will permit, leads us to examine the reasons why various limits are chosen by various people placed in the same situation.

The true probabilities of 1, 2, 3, 4, etc., to 12 successive random occurrences of the same face of a truly unbiased coin are given in Table 7-1. What motivation induces one person to stop and question his assumptions when the odds for the event happening are 1 in 16, while another may have his limit at 1 in 64, or 1 in 256? The answer to this question is prob-

* "Perfect" balance is logically impossible!

TABLE 7-1

No. of Successive Occurrences	Probability		
	Expression	Value	Odds
1	0.50	0.50	1/2
2	0.5^2	0.2500	1/4
3	0.5^3	0.125	1/8
4	0.5^4	0.0625	1/16
5	0.5^5	0.03125	1/32
6	0.5^6	0.015625	1/64
7	0.5^7	0.0078125	1/128
8	0.5^8	0.00390625	1/256
9	0.5^9	0.001953125	1/512
10	0.5^{10}	0.0009765625	1/1,024
11	0.5^{11}	0.00048828125	1/2,048
12	0.5^{12}	0.000244140625	1/4,096

ably a composite of the many philosophical factors which account for the "long-shot player," the "speculator," or the "sure-thing only" gambler!

The Standardization of Confidence Limits

The use of a confidence limit in the foregoing examples is an effort to answer this basic question: If the true probability of an event occurring is p', how far from p', in either direction, may a sample proportion, say, p, depart before it must lead to the conclusion that either one or a combination of the following is true?

1. p' is *not* the true probability.
2. The sample is *not* randomly drawn.
3. The sample was *not* drawn from the same distribution which has been measured or described by p'.

If we place any limit whatever on the extent of the departure of p from p' and if we then draw a sample yielding a proportion beyond the limit, we may expose ourselves to two types of errors in logic:

1. We may conclude that p' is false, when it is really true.
2. We may conclude that p' is true when it is not.

Usually when we sample, we are attempting to measure something, and measure it to a certain standard of reliability. Suppose, after making 1,000 observations in our Work Sampling study, we have found that the occurrences of the Writing category are 200. Therefore, our best estimate of p' is 20.0 per cent. Now let us suppose that a subsequent round of 5 observations shows Writing occurring in all 5 cases. The probability of this happening has been shown to be 0.032 per cent, or about 3 in 10,000. If this probability is beyond our personal confidence limit, we may conclude that:

1. The p' we used does not represent the true proportion of Writing present.
2. The sample proportion p is not a value in which we can have confidence, and that, therefore, p' is still true.

Now observe that, if we adopt the first conclusion (that is, that p' is *not* true), we cannot be *certain* this is the correct conclusion! Neither can we be *certain* that the second conclusion is sure! This problem in uncertainty can be summarized as follows:

	Conclusions Possible	
Truth	Correct	Error
1. Change in p'	Change in p'	No change in p'
2. No change in p'	No change in p'	Change in p'

Thus there are two types of errors possible:

1. We may conclude there *is* change, when there really is not.
2. We may conclude that there *is not* change, when there is really change.

Our objective in the use of confidence limits is to minimize *both* types of errors. While these may appear to be incompatible, experience has shown that a compromise must and can be struck between these errors to minimize cost.

To illustrate our problem, let us return once more to the

coin-tossing case, where different risks of error of both kinds can be illustrated vividly. The person who permits only two successive heads to appear before concluding that the coin is biased is choosing a probability of 0.5^2, or 0.25 as a limit, at which he concludes that p' is not 0.50, but something else. Referring to our diagram above, he is incurring the following risks:

1. If the coin really *is* biased in favor of heads, i.e., the *true* probability is not 0.50, he will be correct to stop the tossing after two successive heads three times in four. Stated another way, the odds are three to one that the coin *is* biased, and one to three that it is *not* biased.

2. If the coin is really *not* biased in favor of heads, i.e., the true probability is 0.50, he will be correct to stop the tossing after two successive heads one time in four, and will be in error three times in four.

In this case, if the bet is a substantial one, it will be better to err in the direction of safety, or the first type of error, to preclude being "taken" at an early stage. On the other hand the consequences of concluding that the coin *is* biased when it is really *not* biased may be disastrous!

In order to be more certain that the coin is really biased, and therefore reduce the chance of reaching the incorrect conclusion when the coin really is biased, we need only accept a smaller limit, say 10 per cent. We pass this point when four successive heads are thrown. At this point, we shall be correct in our conclusion of bias fifteen times in sixteen, and incorrect only one time in sixteen.

If we choose 1 per cent as the long run limit of the probability of being in error, we would allow six consecutive heads to be tossed, but after the seventh head we would call a halt; at this point the probability that p' is really 0.50 is only 0.78125 per cent.

Note that this rationale is based upon the assumption that the probabilities of heads and tails are each 0.50. If we were to begin with the assumption that there *is* bias, we would then expect to see a "run" on heads, and would therefore set our limits according to the values chosen for p' and q'.

In the use of the confidence limits, we are much assisted by adopting the viewpoint that we are really testing whether change *has* taken place, and set our confidence limits to minimize the error of failing to conclude that change has taken place, when it really has.

For these reasons, most statistical confidence limits are designed to *test the hypothesis that change has not taken place.** In this way the risk of failing to identify change is low, and the risk of concluding that change *has* taken place when it really *has not* is also low.

Let us examine this logic. In most sampling efforts extending over a number of samples, and usually an extensive period of time, we are attempting to do one of the following:

1. Estimate precisely a constant value
2. Identify change as it occurs in a variable value

Whether we are using sampling for one or the other, the convenience of working from the hypothesis of "no change" or "stability," and using confidence limits that minimize the risk of failing to identify change, we "catch" deviations more often than we miss them; also, by tending to err in the direction of concluding there *is* change when there is *not*, we shall only infrequently find ourselves looking for causes of change when none is present.

Any pragmatist in business will verify the experience that "nothing is permanent but change." Change is indeed a constant state of affairs, and the Work Sampler, like the industrial engineer, would rather "cry wolf" occasionally, when no

* This is called by statisticians the "null hypothesis."

wolf is there, than fail to be aware of change when it *does* happen.

With this logic in mind, users of statistical tools in various fields have devolved "risk levels" which have become fairly standard. For example, medical analysts seldom draw a conclusion concerning possible danger or death to the user of a new drug until a very tight confidence limit has been adopted and proved. Sometimes a probability of being wrong may be almost microscopic, in the neighborhood of 1 in 100,000. In agricultural and biological experimentation, and in most industrial quality control, a confidence limit of about 1 chance of error in 350 is used. In other applications, an error of 1 per cent or 5 per cent, i.e., a probability of error in failing to identify change, is used.

How to Derive Confidence Limits

In order to establish these limits for the particular sampling problem at hand, some idea of the behavior of "stability" under random sampling conditions is necessary.

Given any *true* proportion p', we have seen that a sample proportion $p = p'$ would not *always* occur, that is, p (for the sample size n) would not always be exactly p'. Our problem in establishing confidence limits is simply the question: "How far from p' may a sample p, found in a sample of n, depart from p' before we should conclude that change has taken place?"

The influence of random sampling conditions on p, a sample proportion, is described by the normal curve of error, discussed in the previous chapter. That this is the case can be proved mathematically, or derived experimentally. Without attempting to prove or derive it here, it can be seen that if we can derive and use some standard deviation measure for a distribution of sample p values, in respect to a p', we can use the

table of areas under the normal curve directly, to derive probabilities of obtaining any sample p proportion.

The formula for the standard deviation of p for any given sample size n is

$$\text{S.D.} = S = \sigma_{p'} = \sqrt{\frac{p'(1-p')}{n}}\dagger \tag{5}$$

if p' is known. This formula is essentially the same for the condition where p' is not known. This, of course, is the usual situation of the Work Sampler. In this case, an average value of p, computed from previous samples, can be used.

Let $\bar{p}$ (read "p bar") represent the historic average value of sample p values,

$$\sigma_{\bar{p}} = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = \frac{\sqrt{\bar{p}(1-\bar{p})}}{\sqrt{n}} \tag{6}$$

If no historic average $\bar{p}$ is available, as would be the case if no previous samples were available, a standard deviation of a single p value can be obtained by

$$\sigma_p = \sqrt{\frac{p(1-p)}{n}} = \frac{\sqrt{p(1-p)}}{\sqrt{n}} \tag{7}$$

The standard deviations derived from formulas (5) to (7) have the same significance as the σ value, found in the previous chapter, for the normal curve, and the same use can be made of it to quickly locate values of p which can be considered as beyond any desired confidence limit.

† Actually, this and succeeding formulas of similar type should be written as

$$\sigma_{p'} = \sqrt{\frac{p'(1-p')}{n-1}}$$

However, since the difference between n and $n - 1$ becomes important in its influence on σ values only when n is about 30 or less, the vast majority of Work Sampling decisions can be made safely by using n directly. When attempting to estimate p' from a single small sample, however, there is very little precision possible anyhow, and use of $n - 1$ will increase σ, making the estimate even more unprecise!

Let us take an example now from Work Sampling. After one round of observations of 30 punch-press operators, 6 are found to be engaged in "loading and unloading coil stock." After this one sample, we can estimate p' for this category no more precisely than as the ratio of 6 to 30 or 20 per cent. The vagaries of sampling will lead us to suspect that successive values of p may not be exactly 20 per cent. But how far from 20 per cent could they be expected to go? If we accept the $\pm 2\sigma$ limit, or a probability of being correct approximately 95 per cent of the time, we could now compute σ_p:

$$\sigma_p = \sqrt{\frac{p(1-p)}{n}} = \sqrt{\frac{0.20(0.80)}{30}} = 0.073 \qquad (7)$$

Laying off $\pm 2\sigma_p$ around 20 per cent shows that our true p' lies between 5.4 per cent and 34.6 per cent. If we set up tighter requirements in so far as error is concerned, say at $\pm 3\sigma_p$ (i.e., demanding accuracy to a probability of about 99 per cent), we can safely say that the true p' lies between 0.0 per cent and 41.9 per cent. These wide limits seem to offer very small reliability to our estimate of p'. This follows naturally, since we have only one sample at hand, and we should not expect great precision.

But now let us take nine more rounds of observations, with the results shown in Table 7-2. Now $\bar{p} = 64/300 = 0.213$, and our ability to lend reliability to it is much greater. Our best single estimate of p' is now 21.3 per cent, and we now can say that p' has a probability of 95 per cent of lying between

$$\bar{p} \pm 2\sigma_{\bar{p}} = 0.213 \pm 2\sqrt{\frac{\bar{p}(1-\bar{p})}{N}} = 0.213 \pm 2\sqrt{\frac{0.213(0.787)}{300}} \qquad (8)$$

where N is used to denote $n_1 + n_2 + \cdots + n_{10}$. The confidence limits so set are now $0.213 \pm 2(0.024)$, or from 16.5 per cent to 26.1 per cent. If we adopted the requirement that our estimate of p' must be correct with a confidence limit of

TABLE 7-2

Sample No.	Sample Size	No. Observed Loading and Unloading Coil Stock	p
1	30	6	0.200
2	30	7	0.233
3	30	7	0.233
4	30	8	0.267
5	30	6	0.200
6	30	4	0.133
7	30	9	0.300
8	30	6	0.200
9	30	4	0.133
10	30	7	0.233
Total..........	300	64	0.213

99 per cent, approximately, the limits would be 0.213 $\pm$ 3(0.024), or from 14.1 to 28.5 per cent. We can now make one additional use of the formula

$$\sigma_p = \sqrt{\frac{p(1-p)}{n}} \tag{7}$$

Substituting 0.213, or $\bar{p}$ in the formula, for p, we have

$$\sigma_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = \sqrt{\frac{0.213(0.787)}{30}} = 0.075 \tag{9}$$

Now the limits within which sample p values should lie, where $n = 30$, can be set at $\bar{p} \pm 2\sigma_p$ or $\bar{p} \pm 3\sigma_p$, and we can examine our 10 samples to see if stability was present during the 10 rounds of observations. Suppose we adopt the 95 per cent confidence limit here.

$$\bar{p} \pm 2\sigma_p = 0.213 \pm 2(0.075) = 6.3 \text{ to } 36.3 \text{ per cent} \tag{10}$$

Examination of our 10 samples reveals that any of these values could occur by chance alone from a true p' of 21.3 per cent, and we can therefore conclude that the conditions of work

during sampling were consistent (more properly, that they did not differ "significantly") and that the conditions of randomness in the sampling were satisfactory.

Suppose that at this point management takes some action to reduce this category. The objective of Work Sampling is not only measurement but also provision for improvement. After the improvement is installed, we would expect sample p values for the category Loading and Unloading Coil Stock to be less. Suppose that samples after the improvement are as shown in Table 7-3. Since a sample proportion of 0 per cent,

TABLE 7-3

Sample No.	Sample Size	No. Observed Loading and Unloading Coil Stock	p
11	30	3	0.100
12	30	2	0.067
13	30	2	0.067
14	30	0	0.000
15	30	4	0.133
	150	11	0.073

as in sample 14, and of two other samples as near our limit as samples 12 and 13, would not occur by chance, we can safely say that there *has* been change. This can be further proved by assuming the true average to be the previous $\bar{p}$, or 21.3 per cent, substituting 150 as N rather than 300, in Eq. (8) above, which then becomes

$$\bar{p} \pm 2\sigma_{\bar{p}} = 0.213 \pm 2\sqrt{\frac{0.213(0.787)}{150}} = 0.213 \pm 2(0.033)$$

The lower limit for $\bar{p}$ from the 150 observations made after the improvement is therefore $0.213 - 2(0.033) = 0.147$, or 14.7 per cent. Since our actual $\bar{p}$ after improvement is 7.3 per cent, we are safe in concluding that the change has reduced

the incidence of this category, that is, its proportionate time, to about one-third of its former amount.

Incidentally, a change such as this should be reflected in at least *one* other category, and perhaps in many other ones, since the reduction of time spent in the category Loading and

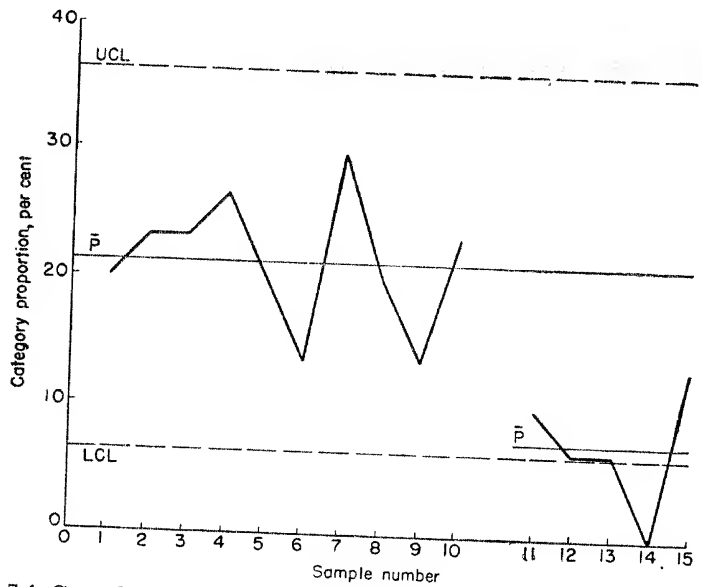


FIG. 7-1. Control Chart for results of Work Sampling study. Category was Loading and Unloading Coil Stock; sample size 30; major material-handling improvement installed between samples 10 and 11; control limits at $2\sigma_p$.

Unloading Coil Stock should make more time available for other activities.

The preceding example can be visualized much more readily if we chart the data on a Control Chart for category proportions, using the method followed in statistical quality control for attributes data. Figure 7-1 illustrates this type of graphic device.

There is great value in charting such data, if for no other reason than that it makes comprehension easier. The value of the Control Chart is enhanced, however, by its soundness

as a mathematical proof of reliability, or stability. While it may be "obvious" that in Fig. 7-1 a change in $\bar{p}$ has taken place, it is nonetheless true that "obviousness" is not a uniformly defined subjective condition. Statistical control, however, has precise and objectively correct interpretive conditions associated with it. We shall now turn our attention to the meaning of the Control Chart.

8

Use of the Control Chart in Work Sampling

Introduction

The development and use of the Control Chart method has been largely in the field of statistical quality control. Its capabilities as an analytical tool are worthy of its use in many other areas of industrial investigation. In fact, generally speaking, whenever a quantitative measurement of a variable can be made, and it is desirable to test this value as it behaves across time, by drawing samples at regular or irregular intervals, seeking to see either *stability or change*, the Control Chart method can be used to advantage.

While the user of Work Sampling is urged to acquaint himself with a fuller discussion of the Control Chart method,* some working rules for its construction, interpretation, and use will be given here.

Types of Control Charts

In Work Sampling, there are two principal types of Control Charts, which we shall call the p chart and the c chart, although the connotations of p and c are slightly different than in the conventional quality control meaning.

* See E. L. Grant, "Statistical Quality Control," 2d ed., McGraw-Hill Book Company, Inc., New York, 1952.

The p chart may be called the "chart for category proportions," and is used to plot percentages found in a single category, or group of categories, in successive samples. This is the basic type of chart for analysis of results.

The c chart may be called the "chart for observations (or rounds of observations) per selected time interval." This chart is used after a study is well under way, in order to ensure randomness in the observation times.

Constructing the Chart

Center Lines

1. p chart. In the course of the first few rounds of observations, a number of p values for a given category, say p_1, p_2, p_3, p_4, etc., are obtained. These values are averaged, and called $\bar{p}$, which becomes the value of the center line on the chart.
2. c chart. The center line of the c chart is the average c value from the study.

Plotting Points. After at least 10 rounds of observations, *or* at least 300 individual observations (based on 10 categories), have been made, the individual p (or c) values are plotted on the chart as shown in Fig. 8-1. Since $\bar{p}$ (or $\bar{c}$) represents the center line, these individual p (or c) values will occur on both sides of the center line.

Selecting the Scale. The scale (vertical) for the chart should be designed in order to satisfy three conditions:

1. It should be easy to read.
2. It should permit plotting of the largest expected value.
3. It should always originate at the value 0, or zero, in order to preserve the relative amount of deviation from point to point.

Establishing Limit Lines. The setting of limits within which points should lie can be done in two ways:

1. By using sample p values from the study itself
2. By deciding in advance what proportionate departure from the center-line value will be permitted

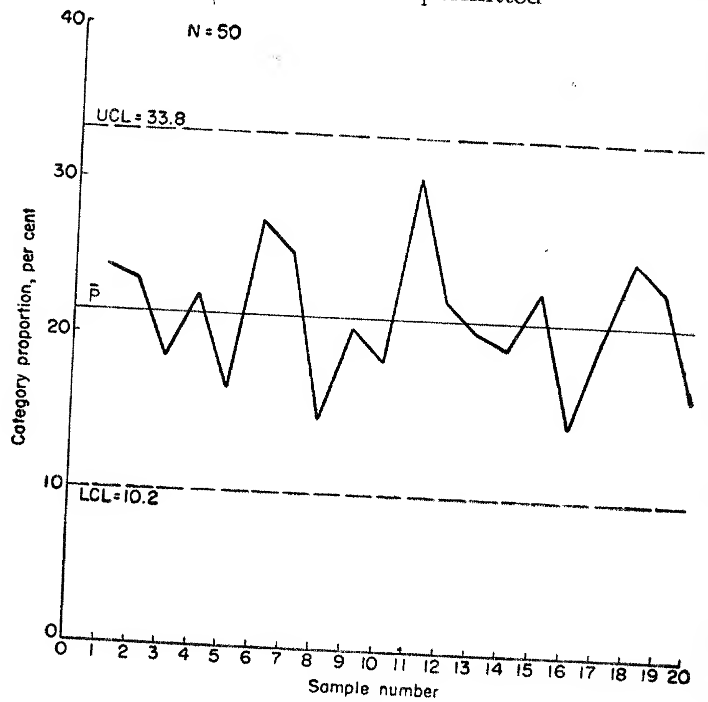


FIG. 8-1

The second method is appealing, perhaps, but seldom practical. Discussion of this method will be reserved for a later section.

When at least 10 samples are available, as stated above, and $\bar{p}$ is derived, the use of our formula (6), page 95, can be used to obtain σ_p. Laying off $\pm 2\sigma_p$ or $\pm 3\sigma_p$ around $\bar{p}$ establishes these limits at approximately the 95 per cent and 99 per cent confidence limits, respectively.

When using the c chart,

$$\sigma_c = \sqrt{\bar{c}}\dagger$$

† For derivation, see Grant, *op. cit.*

Again, laying off $\pm 2\sigma_c$ or $\pm 3\sigma_c$ locates the 95 per cent or 99 per cent confidence limits, respectively.

Choosing between 2σ and 3σ Limits. Strict interpretation of the limits would be as follows:

1. *In the long run, if $\bar{p}$ (or $\bar{c}$) is the true average, then only one point in* 20, *on the average, should lie beyond any* 2σ *limit, or only about one in* 100 *points should lie beyond any* 3σ *limit, if statistical stability is present.*

2. If a point or points occur beyond the limit lines, we should conclude that stability is *not* present, and attempt to identify the reason for the change in $\bar{p}$ (or $\bar{c}$). While one time in 20, or one time in 100, we shall be seeking a cause of change when none really exists, we shall be correct in seeking such a cause, on the average, 19 times in 20, or 99 times in 100.

Whether to select $\pm 2\sigma$ limits or $\pm 3\sigma$ limits or any other set of limits, is really a problem in *balancing risks.* Based upon experience in many Work Sampling situations, it is recommended that the following reasoning be used:

1. Select $\pm 2\sigma$ limits when *beginning* a Work Sampling study.
2. Use $\pm 3\sigma$ limits after stability at a desirable economic level has been achieved.

When a study is begun, and the objective of the study is to measure the proportions of time now being spent in the categories chosen, the $\bar{p}$ obtained for some of the categories normally proves to be too high or too low to be considered a tolerable proportion. This is logical, since improvement is the ultimate objective of any Work Sampling study. If $\pm 2\sigma$ limits are used (a more sensitive indicator of instability if the risk of error is tolerable), we will be able to discern change faster than if $\pm 3\sigma$ limits are used. Normally, as improvements in the distribution of category proportions are achieved, we will be able to revise our $\bar{p}$ values more quickly, and hence measure the extent of the improvement.

As improvement efforts yield results desired, we should expect to see stability in the category proportions at more desirable levels. Therefore, we should then attempt to minimize the risk of seeking causes of change when they are really not present. This can be done by adoption of $\pm 3\sigma$ limits after the desired distribution of time has been reached.

One factor in this choice which may affect our selection of limits in the above way, however, is our dependence on *random* sampling. Sometimes nonrandom influences are present, particularly in the early stages of a study, e.g., an observer deliberately failing to record a category when it occurs, and recording it as something else; or nonrandom intervals being used between observations; or any other biasing influence on results. When these types of nonrandom effects are present, or are suspected to be present, a $\pm 3\sigma$ limit should be used on category proportions until these influences are removed. *In fact, as long as they are present, any limits used, around $\bar{p}$, have no statistical significance.* It is vital that the conditions of randomness be fulfilled.

Interpretation of the Control Chart

THE APPEARANCE OF STABILITY. By defining the appearance on a Control Chart of a stable distribution (i.e., deviations in p, or c, values occur only through chance), we can derive rules for detecting *instability*. In general, a control chart for a stable distribution of p, or c, values should exhibit the following characteristics:

1. All points should fall within the limit lines.
2. Points should cluster near the center line.
3. Points should occasionally dart out near the limit lines.

The easiest way to visualize this is to think of a chart where the points occur without any apparent order, but where, after 50 or 100 points have been plotted, the chart could be laid on

its vertical axis, and the points dislodged and "shaken down" perpendicularly to the axis, when they would create a normal curve appearance. Figure 8-2 illustrates this analogy.

With this established, what then are the appearances of instability? For Work Sampling purposes, *assuming randomness* is present, the patterns of instability can be classified into four main types:

1. Mixture
2. Cyclic effects
3. Trend effects
4. Stratification effects

Mixture. This term is used to indicate a mixture of essentially different distributions of p (or c). Figure 8-3 is an example of this.

When we sample from two or three different distributions without knowing it, our p values obtained will depend upon the proportion of the sample items drawn from each. This is analogous to drawing a sample consisting of both apples and peaches, and attempting to average the two, in order to draw a conclusion about the apples!

For the Work Sampler, the appearance of mixture may occur for several reasons:

1. He is averaging p values from more than one type of job, or machine operation, or other cause of difference in time distributions. To correct this cause of mixture, the jobs or component groups must be broken out sufficiently finely as to deal with only one distribution at a time.

2. He is sampling from the same distribution, but the distribution proportion (i.e., the real proportion of time spent in the category) is widely fluctuating and seldom stable, usually because of differences in method, supervision attention, operator training, machine efficiency, machine condition, etc. Usually these are caused by lack of sufficient and proper man-

agement attention. To correct this cause of mixture, some effort must be made to standardize the conditions causing its appearance.

Cyclic Effects. Frequently the Work Sampler is faced with a periodically fluctuating condition, sometimes at regular and

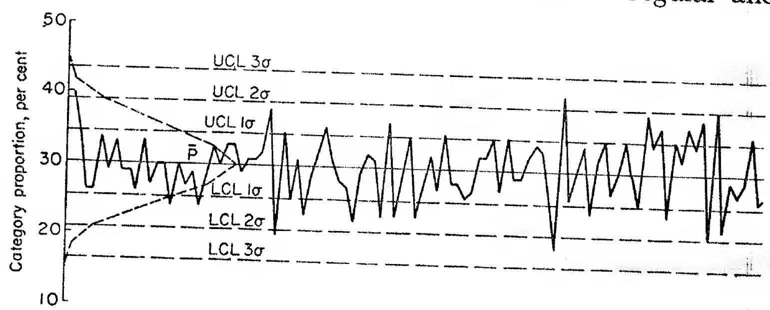


FIG. 8-2

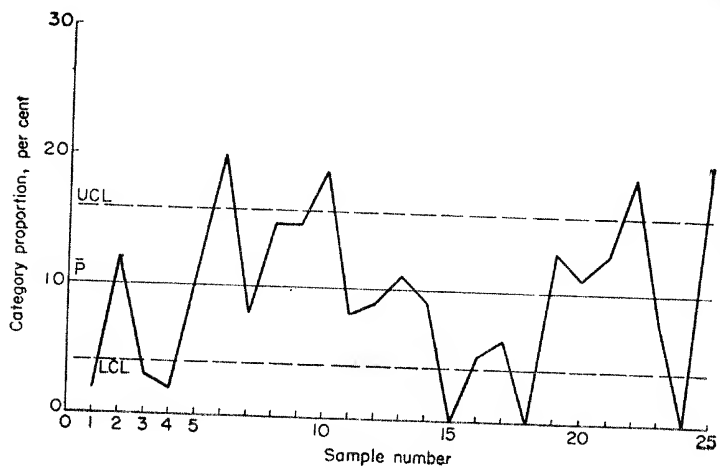


FIG. 8-3

predictable intervals, where volume of work load, proportion of equipment utilization, or other known factors are the causes. In this case, the behavior of p values during the cycle will vary directly or inversely in a rhythmic manner. This condition is perhaps a type of mixture, but occurs with sufficient frequency to be identified separately.

The pattern of the Control Chart under cyclic conditions of work should reflect the extent of the influence of the cycle on p value distributions. It is reasonable, therefore, to expect the value of $\bar{p}$ to be high at some times and low at others. In fact, $\bar{p}$ may be changing almost constantly because of these cyclic influences.

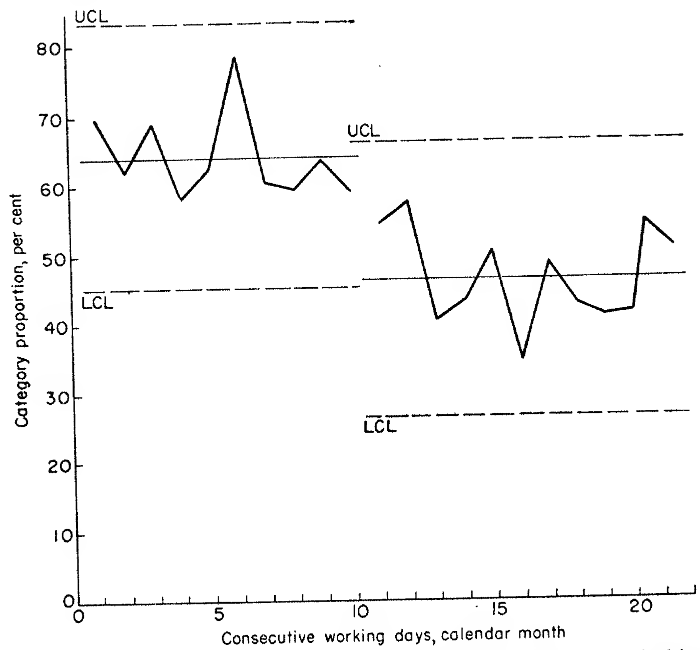


FIG. 8-4. Example of two distinct activity levels during month. Machine accounting operation; sample size 25; control limits at 2σ. Note that point 11 is out of control for first $\bar{p}$ by nonparametric test.

When definite and discernible levels of activity are present, different levels of $\bar{p}$ should be determined, and limit lines established for each. It is important, however, to note that when this condition is present, all categories do not necessarily change their $\bar{p}$ values proportionately! Figure 8-4 is an example of a situation where two distinct levels of $\bar{p}$ are used.

Trend Effects. As a Work Sampling study proceeds, improvements should be made which have the effect on $\bar{p}$

values desired by management. The direction of the movement desired in $\bar{p}$ may be up, as in the case of Fig. 8-5, or down, as in the case of a nonproductive, avoidable category.

A gradual improvement, or trend, may take place which takes quite a long while to appear as a point beyond a limit line on the Control Chart. There are, however, ways available to detect these gradual changes before a point actually exceeds a limit. In statistical quality control, these methods, or tests, are known as "nonparametric" tests for instability.

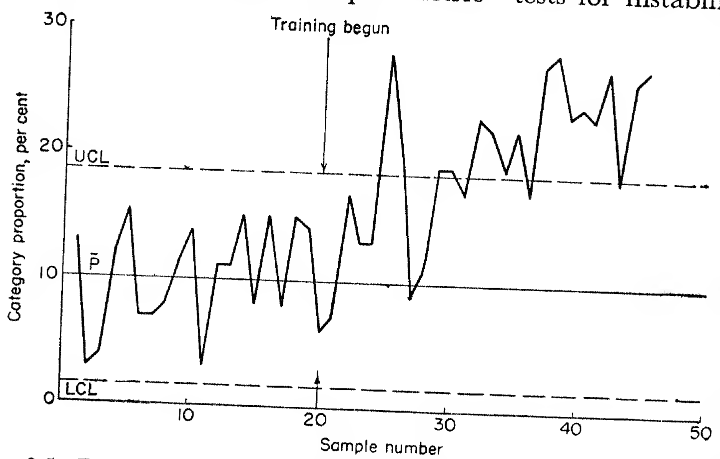


FIG. 8-5. Example of a measurable improvement—observations of foremen on the job. Category was Supervising and Planning Work; sample size 50. $\bar{p}$ was established after first 20 samples.

In general, they are based on the statistical theory of "runs" above and below a center line. In their simplest form, they reduce to the following:

A change in the value of $\bar{p}$ may be considered as having taken place under these conditions:

1. Using $\pm 2\sigma$ limits
   a. When two or more consecutive points occur between $+1\sigma$ and $+2\sigma$, or between -1σ and -2σ
   b. When five or more consecutive points occur on the *same* side of the center line, but within the limit on that side

2. Using $\pm 3\sigma$ limits
   a. When, in any set of three consecutive points, any two lie between $+2\sigma$ and $+3\sigma$, or -2σ and -3σ, the third occurring anywhere else, between the limits
   b. When, in any set of five consecutive points, any four lie between $+1\sigma$ and $+3\sigma$, or between -1σ and -3σ, the fifth occurring anywhere else, between the limits
   c. Whenever eight or more consecutive points lie on the same side of the center line, but within the limit, none exceeding the limit line
   d. When, in a set of eleven consecutive points, any ten are on the same side of the center line but within the limit, the eleventh being on the other side, but within the limit on that side
   e. When, in a set of fourteen consecutive points, any twelve are on the same side of the center line but within the limit, the remaining two being on the other side, but within the limit on that side

Having rules such as these* available enables the Work Sampler to detect trend effects more easily and quickly.

STRATIFICATION EFFECTS. The word "stratification" implies strata, or layers, being present. This is its literal meaning here, as can be illustrated by its appearance on a Control Chart, Fig. 8-6. One of the requirements of a stable pattern was the occasional darting of points out near the limit lines. When points tend to cluster at about the same value on the chart, we can usually conclude that some systematic error is present in sampling.

For example, in a maintenance study, involving a number of rapidly reassigned mechanics, the foreman, who was the observer, was found to be stratifying the results of his study

* For a derivation of these nonparametric tests see Grant, *op. cit.*, pp. 217–218.

by observing the same pair of men much more frequently than others, and some other men hardly at all. For this reason, the values of $\bar{p}$ tended to appear *too* stable. Investigation in this case soon revealed the cause, and the observer corrected this systematic bias. Note here that the cause was not a nonrandom influence in so far as observation *time* was concerned, but a nonrandom influence in respect to the probability of observing any one *person!*

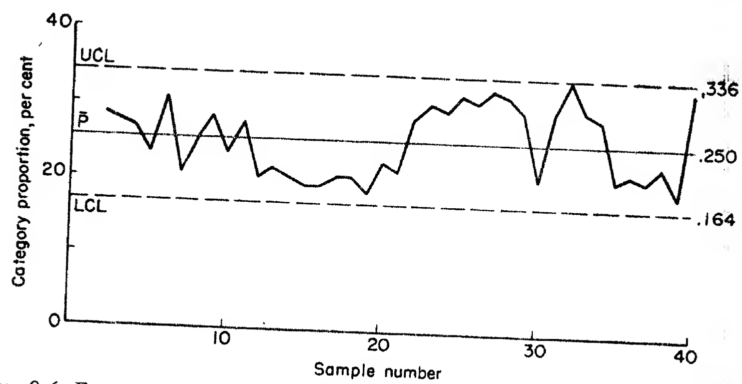


FIG. 8-6. Example of appearance of stratification in a Control Chart. Category was Travel in a study of hospital nurses. $\bar{p}$ was established from previous studies. Observer tended to record certain persons more, or less, than others over extended periods. Sample size was approximately 100; control limits at $2\sigma_p$.

Correction of stratification can be made only by locating and removing the cause of it. The nonparametric tests are powerful weapons in this problem of detection of stratification.

How to Achieve Randomness

RANDOM OBSERVATION TIMES. A number of ways are available for assigning observation times so that the interval between observations is randomly distributed, but the easiest method for people to understand and use involves a table of random numbers, such as Appendix 1, Random Sampling Numbers.

Randomness may be desired within any given period of

time, depending on the use of the study, the period during which observations are to be made, and the extent of within-week or within-hour volume fluctuations. If an observer is expected to make a round of observations on the average once an hour, randomness within each hour is probably the basis which will be sought. If, say, five rounds per day will be made, randomness across each 8-hour day will be easy to fulfill; while if the study is to be a long one (say, 3 months), randomness within each 40-hour week can be obtained.

A table of random numbers is derived by a method almost exactly equivalent to putting 10 chips, numbered 0 to 9 into a hat, stirring them up thoroughly, drawing one by chance, recording its number, replacing it; stirring, drawing, recording, replacing, etc., many times. The statistical theory pertinent to this may be found in most textbooks on quality control.

The result is a simple listing of numbers, not arranged in any ordered way, and which can be read horizontally, from left or right, vertically from top or bottom, diagonally, or in any other way, since each number occurs on the page in a random way. Thus we can select one, two, three, or any consecutive number of digits which we may want, as they appear. To illustrate the use of a table of random numbers, let us take two examples: (1) Observer to take eight rounds of observations per eight-hour shift. (2) Observer to make five rounds of observations per eight-hour shift.

1. Using a table of random numbers, the observer records each successive two-digit number from 00 to 59, as he comes to them, beginning, for example, in the upper left-hand corner. The first number is 07, which becomes 8:07 A.M.; the next is 25, which becomes 9:25 A.M., etc. Thus for a 2-week study, the schedule in Table 8-1 would appear.

If half-hourly intervals are desired, record successive two-digit numbers from 00 to 29.

TABLE 8-1

Day No.	A.M.				P.M.			
	8:XX XX =	9:XX XX =	10:XX XX =	11:XX XX =	1:XX XX =	2:XX XX =	3:XX XX =	4:XX XX =
1	07	25	44	08	38	01	04	13
2	52	22	30	39	44	13	50	57
3	39	54	37	58	41	11	08	12
4	12	31	00	17	25	06	00	45
5	06	47	09	53	42	51	42	21
6	03	20	05	35	30	06	12	09
7	55	09	36	54	52	28	24	30
8	09	56	31	50	08	37	42	43
9	58	24	41	29	21	42	04	29
10	33	20	51	04	27	12	31	20

2. Since a day of 8 working hours contains 480 minutes, numbers from 000 to 479 can be selected, and considered in groups of five. These five are then arranged and added to the starting time. As an example, see Table 8-2.

In the case where a prescribed or contractual "rest period"

TABLE 8-2

Random Numbers		Array	Time
1	078	010	8:10 A.M.
2	254	078	9:18 A.M.
3	472	083	9:23 A.M.
4	083	254	1:14 P.M.
5	010	472	4:52 P.M.
1	413	222	11:42 A.M.
2	222	303	2:03 P.M.
3	303	350	2:50 P.M.
4	441	413	3:53 P.M.
5	350	441	4:21 P.M.
1	395	108	9:48 A.M.
2	478	378	3:18 P.M.
3	378	395	3:35 P.M.
4	411	411	3:51 P.M.
5	108	478	4:58 P.M.
	etc.	etc.	etc.

is used, no observations should be scheduled during the exact nominal interval itself, in order to prevent occurrence of opportunity to misinterpret results of the study. After all, the round of observations made during such an interval will certainly not yield a contribution to our knowledge of the *working* time distribution!

If the random numbers happen to occur in such a manner that a subsequent round is to be begun before a previous round is completed, another time should be substituted for the second round, by simply using the next random number as it appears in the table. For example, in (1), above, on the seventh day, rounds of observations are scheduled for 8:55 and 9:09 A.M. If at least 15 minutes are required to complete the round, the 9:09 should be replaced with 9:41, since 41 is the next two-digit number less than 60 appearing in the table.

Sometimes, the assignment of observation times is inexpedient, especially when dealing with operations such as widely scattered maintenance or construction work, when the foreman is the observer. In these cases, a method should be provided for the observer to record the times when observations were made, by intervals used as the periods within which randomness is desired. Figure 8-7 is an example of such a method.

The form shown as Fig. 8-7 was given to the foreman each month. As he made successive rounds of observations, he put an X in the next open block corresponding to that time, working from the left. He was expected to make about 90 rounds of observations per month, and this is indicated by the center double vertical line. The heavy vertical lines bracketing the double heavy line were established as the least and most rounds per interval by the Work Sampling supervisor. As the foreman proceeded during the month, he found it possible to "keep score" himself and thus be sure he covered each interval adequately.

WORK SAMPLING
MONTHLY RECORD OF TIME PERIOD USAGE

Observer Name____________________

Observer No.____________________

Month____________________

Time Periods	Number of Observation Trips											
	1	2	3	4	5	6	7	8	9	10	11	12
0730–0745												
0800–0815												
0830–0845												
0900–0915												
0930–0945												
1000–1015												
1030–1045												
1100–1115												
1130–1145												
1200–1215												
1230–1245												
1300–1315												
1330–1345												
1400–1415												
1430–1445												
1500–1515												
1530–1545												
1600–1615												
	1	2	3	4	5	6	7	8	9	10	11	12

Use of Chart

1. After taking an observation trip, place an X in the time period row that corresponds to the time the trip was taken. Begin at the left-hand side of the chart.
2. When a time period already has been used (marked with an X) and is to be used again, mark X next to the previous X. Thus the chart is built from left to right as the month progresses.
3. At the end of the month, the last X in each row should lie somewhere between the two heavy single lines, *or* the difference between the greatest number of X's and the least number of X's in any row should not be more than ______.
4. During the latter part of the month, attention should be put on those time periods that have the least number of X's.

FIG. 8-7

Use of the c Chart to Test for Randomness

Sometimes it is impossible for an observer to make a round of observations at the scheduled time, in which case the round may be missed entirely, or taken as soon thereafter as possible. No appreciable effect on the basic randomness of the study will necessarily result, since the causes of the missing of observations may themselves be randomly distributed. It is good practice, however, to check periodically on the adherence to the basic requirement of randomness. This can be done quite

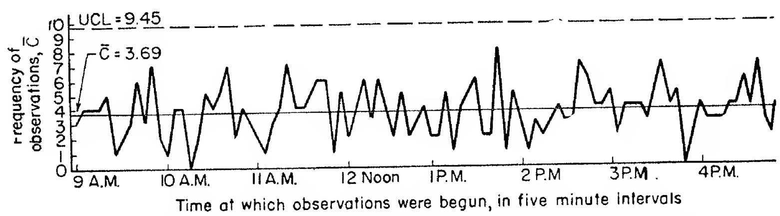


FIG. 8-8. Control Chart for observations per 5-minute interval, March 15 to May 15, 1954.

$\bar{c}$ = mean number of observations (cycles) within the 5-minute period
$UCL_{\bar{c}} = \bar{c} + 3\sqrt{\bar{c}}$ = upper control limit
$LCL_{\bar{c}} = \bar{c} - 3\sqrt{\bar{c}}$ = lower control limit
Total observations (cycles) = 354
Total observations (individuals) = 6,122
Total people observed = 27

easily by use of the c chart, the chart for observation rounds (or observations) per selected time interval. This chart shows whether the working period was covered uniformly, that is, no one time was favored or unduly avoided by the observer.

Such a c chart is shown in Fig. 8-8, where it can be noted that an average number of observation rounds per 5-minute period was 3.69. Control limit lines (at $\pm 3\sigma_c$) were established, the points plotted, and excellent stability is shown. The same data, plotted by 10-minute, 15-minute, 30-minute, and 60-minute intervals, also exhibited stability. In this study, many of the observation rounds were missed, and many taken at times other than those assigned in advance.

The basic c may be defined in two ways:

1. Observation rounds per time interval
2. Observations per time interval

Figure 8-8 is drawn for the first definition of c. When observations themselves are used as c, then a much narrower dispersion can be permitted than is shown in Fig. 8-8.

For Fig. 8-8, the total number of rounds of observations was 354. Total man-observations, however, were 6,122, or about 17 persons per round, on the average. Using 96 intervals of 5 minutes each, $\bar{c}$ based on *rounds* of observations is 3.69, or 354/96. If man-observations per interval, however, are plotted, $\bar{c}$ is 6,122/96, or 63.77. The limit lines for $\bar{c} = 3.69$ are:

$$\bar{c} \pm 3\sqrt{\bar{c}} = 3.69 \pm 3\sqrt{3.69} = 3.69 \pm 3(1.92)$$

Limits are 0.00 and 9.45. The limit lines for $\bar{c} = 63.77$ are

$$\bar{c} \pm 3\sqrt{\bar{c}} = 63.77 \pm 3\sqrt{63.77} = 63.77 \pm 3(7.99)$$

Limits are 39.80 and 87.74. By inspection of these limits, it can be seen that if random times for rounds of observations are made, and assuming 17 persons observed per round, from 17(0.00) to 17(9.45), or 0 to 160, man-observations per interval would be allowed, whereas if a random distribution of *man-observations* per 5-minute interval were demanded, from 40 to 87 would have to occur! Expressed in a different way, from 0 to 9 observation rounds per 5-minute interval would suffice if randomness for the distribution of *rounds* of observation is desired, whereas from 39.80/17 to 87.74/17, or from 3 to 5, rounds would be necessary for randomness of individual man-observations. It is apparent, then, that in order to achieve randomness of individual observations, a very tightly defined number of observations in a specified time interval must be used.

In most Work Sampling practice, the use of randomly dis-

tributed times for *rounds* of observations is all that is required. The only case where the randomness of man-observations should be attempted is where partial rounds, or highly variable sizes of groups observed during different times in the day, are present.

Other Uses of the Control Chart in Work Sampling

After a considerable number of observations have been made, it may be desired to study the differences in time distribution by individual workers, or individual machines, being observed. While a Work Sampling study should never be used as the basis for punitive action in regard to individual employees, it is a valid basis, when sufficient data are available, for training effort where improper methods, causing substandard production, are being used. A p chart showing the distributions of observations for several employees or machines can be truly revealing as an aid to training and to machine replacement decisions.

Case studies in the latter part of this book show several other uses of the Control Chart in Work Sampling studies.

9

Evaluating and Presenting Results of Work Sampling

In evaluating and presenting the results of Work Sampling, there are four distinct procedures to be considered. These are:

1. Evaluating the validity of data
2. Evaluating the reliability of data
3. Presenting and analyzing data
4. Planning for future studies

Evaluating the Validity of Data

In the first procedure, a premium is placed on the alertness of the director of the study and on the soundness of the preparatory steps in the study. The dictionary defines "valid" as "based on evidence that can be supported." For our purposes this means that the results of the study should be able to meet the test of agreement with other reliable measures which, while they may measure only a part of the information gathered in Work Sampling, should be correlated with the study results wherever possible. Evaluation of validity is really an evaluation of the entire process of gathering and recording the basic data.

Three things are necessary to evaluate the validity of a Work Sampling study. These are:

1. Alertness and objectivity on the part of the director of the study. In a word, he must be a "bird dog."

2. Familiarity with, and understanding of, the principles and techniques of statistics discussed in Chaps. 6 to 8.

3. A complete record of conditions surrounding the taking of observations, including measures of production.

In Work Sampling, as in other measurement techniques, a certain amount of error may be expected. One of the advantages of Work Sampling is that since it has its foundation in statistical practice, errors may be identified and classified somewhat more easily than if more subjective means are involved. But these errors must be recognized as such, they must be defined and quantified, and they must be corrected. Primary responsibility for all of this rests with the director of the study.

What form do such errors take? Most causes of low validity are systematic errors which arise as a result of misunderstanding or failure to follow proper technique in gathering data. As examples, consider the following:

1. Failure of the observer properly to identify personnel. This resulted in the inference that personnel were not properly assigned to jobs. It was detected when the data were summarized and corrected by discussion with observer.

2. Failure of observer to note "special" conditions. In this case, hazardous conditions were made the subject of a special set of working and safety rules. The observer treated two days' operation under these conditions as if they were normal days. The director noted the change in study results and corrected the situation.

3. Failure of foreman to notify observer of process change. In this case the changes were not apparent to the observer. Previous agreement to notify observer was violated. Again, the director "caught" the change and corrected the study.

Basically, all these situations could have been averted by proper attention to detail and better training. But since the technique may be new in the shop, and the shop personnel may be unaware of the importance of identifying shop conditions for purposes of the study, errors are made.

There will be no further discussion here of the statistical principles and techniques described in Chaps. 6 to 8. It is sufficient to say that the director must use these techniques to test the data and that he must be on the alert for points which do not exhibit the proper stability on his Control Charts, or for other evidences of systematic error. He must be particularly alert for any pattern of instability which indicates mixture of essentially different distributions of p.

Once recognized, an error which may be the cause of low validity must be corrected at the source. Here is the point at which proper preparation for the study "pays off." If it is possible to go back and reconstruct the situation under which the study observations were made, correction is possible. If something has occurred which was a significant change in conditions, but of which no record was kept, the director is helpless indeed. All he can safely conclude is that a change has taken place. It is therefore of the utmost importance to think through the definitions of categories in order to provide a means of comparing each proportion possible with some other measure. Also, the observers should be impressed with the importance of noting unusual conditions. Here again, the advantage of having supervisory personnel act as observers becomes obvious.

In most cases, only a few of the categories may be verified. It is important that this verification be done, because if one category turns out to have an error of some size, the entire study becomes suspect. This is true because *some* classification was made of the activity. If the correct category was not

selected, the observation must have been recorded in an incorrect category, and a corresponding error must appear there. This very fact makes it possible to cross-check the proportions of observations in each category as an aid to validation.

Evaluating the validity of data is an essential step in a good Work Sampling study. It enables the director to have the proper degree of confidence in the result. It may serve as the basis for simplification of record keeping. Finally, if there appears to be an unexplained systematic error, the first steps will have been taken in the identification of such error. If a shop or office is *not* operating as management thinks it is, positive indication of this fact certainly is of value. In any event, if the condition that the results are valid has been satisfied, presentation of data can go forward. If low validity is present, the causes of this will be of interest to management, and costly mistakes may be avoided.

Evaluating the Reliability of Data

Chapters 6, 7, and 8 have presented the statistical procedures for the performance of this step. The purpose of this discussion is to point out that the reliability of Work Sampling data depends primarily upon the number of observations, *if* the observations were taken under random sampling conditions. Actually, an almost continuous evaluation of reliability should be in progress as the study is made. When the desired degree of reliability has been established, the fact should be evident through tests for this which are outlined in Chaps. 6, 7, and 8.

In evaluating the reliability of results of Work Sampling, the end uses and objectives of the study must serve as the ultimate criteria. The basic question is an economic one. It is always possible to take more observations and thus increase the reliability if stability is present. But what degree of reliability is

needed? When do we reach the point of diminishing returns? What is the practical level of reliability? The answers to these questions are contained in another question: "To what use will the study be put?"

Referring to the uses of Work Sampling in Chap. 4, the degree of reliability required in general increases in the order of the list. A good way to make an evaluation of this sort is to calculate the 95 per cent confidence level, and then decide whether in each case the actual figures for these limits will be acceptable. No rigid rule can be established. The 95 per cent level is suggested because in most cases this represents a level that is reasonable and well understood. In other words, most managers will accept figures that will be consistent nineteen times out of twenty.

The exception to the general rule occurs when the results of Work Sampling are to be used in conjunction with existing time standards set by other methods. In this case, the reliability of Work Sampling results should be consistent with the known reliability of these other time standards. This is not as demanding a condition as it may seem. At the 95 per cent confidence level, for example, both stop-watch time study and predetermined human work times usually exhibit reliability of no better than plus or minus 10 per cent. Lehrer* in time study and Lazarus† in predetermined human work times support this view. A word of caution, however, is in order. Individual structures of time standards in particular shops and offices may attain greater or less reliability than the figure cited as typical. And it is the particular degree of reliability which must be used as the basis of comparison. Determine the reliability of existing time standards in *your own* situation,

* R. N. Lehrer, Doctoral Dissertation (unpublished), Purdue University, June, 1949.

† I. P. Lazarus, Doctoral Dissertation (unpublished), Purdue University, June, 1952.

and strive for a degree of reliability in Work Sampling that is consistent with it.

Finally, in determining goals of reliability, the Control Chart approach is invaluable. The Chart for Category Proportions technique will enable the director of the study to obtain a grasp of the behavior of results which should be of tremendous assistance in deciding upon levels of reliability to be sought. The Chart for Category Proportions, the end use of the study, and the judgment of supervision as to what reliability is *needed* should enable a proper appraisal of reliability to be made.

Presenting and Analyzing Data

The basic data resulting from a Work Sampling study are a series of proportions or percentages of observations which have been classified into the various categories. In general, each observation includes notation of the following variables:

1. The person or unit of equipment observed
2. The time of observation
3. The category into which the observed activity, state, or condition is classified
4. Surrounding conditions (such as type of production, unusual shop situation, etc.)

Any presentation of results must come from analysis of these variables, and all tables, charts, and graphic displays have as their basis only the Work Sampling observations. Therefore the planning stages of a Work Sampling study should be made a matter of attention not only by those who will perform the sampling, but also by those who will base decisions upon the results.

It is a fundamental of the selection of categories that combination of categories is possible, but division is not. Therefore the initial degree of fineness of categories will determine the

detail in which results may be presented. One of the reasons for using punched cards in processing Work Sampling data is that it is desirable to examine closely a *number* of variables, and perhaps to present results in a *number* of different ways. Under such circumstances, punched cards may be useful and economical.

In presenting the results of a Work Sampling study, the proportions or percentages may be given more meaning by the following techniques:

1. Combining categories into broad classes, such as Useful, Service, and Delay activity.

2. Expressing results directly in terms of dollars spent in various categories. This is particularly useful in equipment studies.

3. Charting results on a time axis, to show trends and peak-load conditions.

4. Charting or tabulating Work Sampling results to show the relationship of these to measures of output.

These suggestions by no means begin to exhaust the list of methods of presentation of Work Sampling data. Results may be organized by shop area, by job classification, by types of job worked on, or in many other ways. Categories may be grouped to reflect time-study categories, direct versus indirect labor, production delays, or similar measures used by supervision.

The most common organization of summary sheets for data collection is to tabulate personnel or machines against the category of activity observed for each, and to summarize by the day or week on separate sheets. When specific questions arise, reorganization of data becomes necessary. Also, the same type of report will *not* be made for each level of supervision. It is up to the director of the study to ascertain management *needs* with respect to reporting of Work Sampling

results. Within the limitations of category description, reliability, and validity, he should see to it that these needs are met. A Work Sampling study is effective only to the extent that it is *used.* The reporting of results, therefore, must be done in such a manner that meaningful information of the proper degree of detail is put in the hands of management decision makers. The criterion should be "What action is initiated as a result of this report?"

Some examples of presentation of Work Sampling data are as follows:

Table 9-1 is a table of over-all proportions, by categories and by type of equipment, of a study made of tabulating equipment. Personnel were not studied. This table indicated the total of activity. It did not indicate work-load fluctuations.

TABLE 9-1. CATEGORIES USED IN TABULATING DEPARTMENT STUDY

	Category						
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
Total, all machines.......	33.5	14.3	1.8	1.5	45.0	2.1	1.8
Key punch (6 machines)..	47.7	19.5	0	1.5	25.4	0.5	5.4
Tabulators (3 machines)..	23.9	13.2	11.0	4.4	46.0	1.5	0
Sorters (3 machines)......	37.8	20.8	0	1.0	30.9	9.5	0
Multiplier, interpreter, verifier, interfiler (1 each)	20.5	3.9	0	0.1	75.2	0.3	0
Bookkeeping machines (3)	24.4	11.8	0	0.9	62.6	0.3	0

1. Operating and running
2. Operating—not running
3. Summarizing
4. Not running, but set up to run
5. Available (no job to put on machine)
6. Maintenance (not available)
7. Trainee

Figure 9-1 is a chart showing the data from the table above, but organized along a time axis to show work-load fluctuations and the interrelationships of demand upon the different types of equipment.

Figure 9-2 is a chart showing the dollar distribution of the same activity. This is particularly appropriate in equipment

studies, since costs may vary more than is the case in hourly wage rates.

Other similar charts are shown in the later chapters which give examples of complete studies.

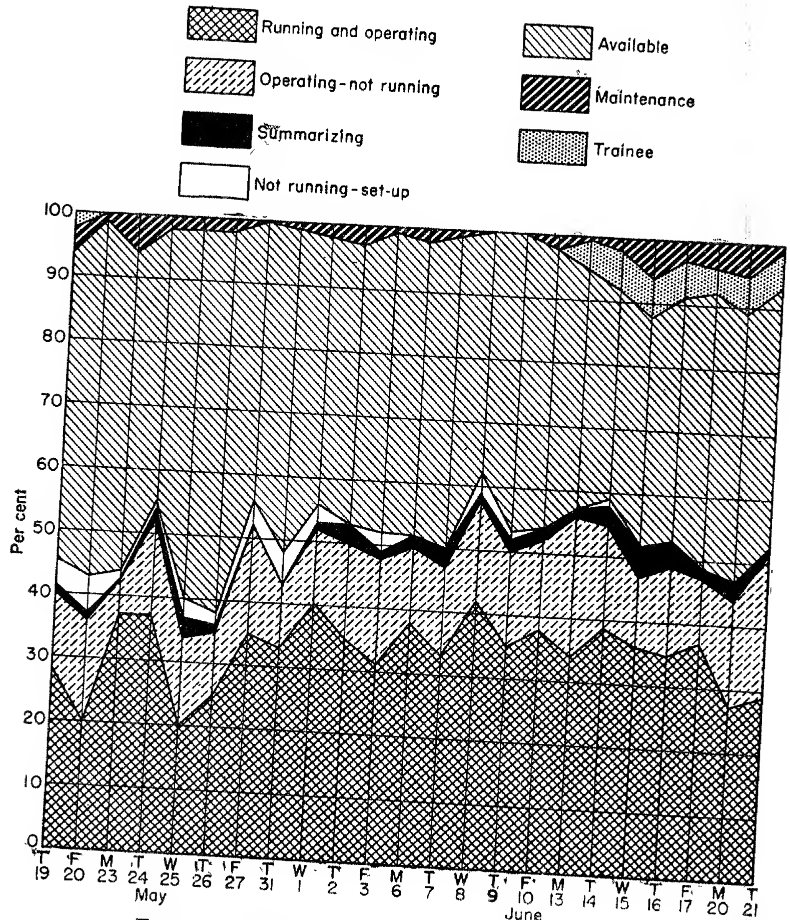


FIG. 9-1. Typical chart of work-load fluctuations.

In addition to the broad analysis expressed in charts, there are many cases in which a particular proportion or percentage is of interest. For example, consider the following:

1. A textile mill wanted to establish how much in labor time

a certain type of customer service cost. A Work Sampling study revealed that loom change-over to meet this demand was 1.7 per cent. Pricing and production decisions could be made on the basis of this figure.

2. A design department wanted to know how much time was spent in revisions of blueprints. This information was necessary in planning the work of designers and checkers.

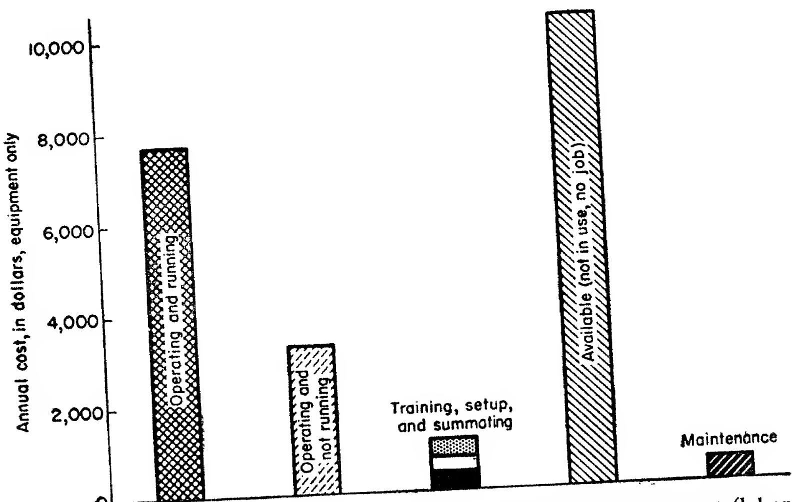


Fig. 9-2. Cost of various activities of machines in tabulation department (labor *not* included).

3. A group of six engineers working in one office had asked that an additional telephone be installed. Work Sampling indicated that only 0.6 per cent of the time were both presently installed telephones in use simultaneously. No additional telephone was installed.

4. It was found in a hospital study that student nurses were receiving formal instruction from graduate nurses only a small (1.3 per cent) proportion of the time. This was far below the desirable amount of time for such instruction.

5. An expensive precision grinder was observed to be in use

by machine operators mainly for offhand and rough grinding. Instruction in tool care was started, and a cheaper machine was put into use.

The great advantage of Work Sampling in cases such as those cited above is that the information is gathered almost as a by-product of the study. Also, the results are expressed in numerical form, with a known reliability. This enables decisions to be made based on fact. Figures of speech such as "a lot" or "not much" may be useful in general discussion, but numerical results are more appropriate to the making of economic choice.

To summarize, the basic data of Work Sampling are expressed as proportions of time. The variables present are those of personnel or equipment, category of activity, surrounding conditions, and time of observation. It is up to the director of the study to combine and arrange these into reports and graphic presentations which will enable the recipient of each report to take whatever action is appropriate. It is expected that a number of different presentations will be made from the same basic data. Finally, the director of the study should be sure that the reports are what the user *needs*.

Planning for Future Studies

Throughout the text constant reference has been made to the Work Sampling study. This is an appropriate term, because at some agreed-upon point it usually may be said that the initial objectives have been met and that a review of progress and an evaluation of results are in order. The factors affecting the point at which this review is done are the number of observations necessary to obtain proper reliability, and the monthly, weekly, or other cyclic conditions which it is considered desirable to encompass in the study.

Action taken as a result of review and evaluation depends

upon the nature of the study and upon the conditions revealed by the study. In many cases the first use of Work Sampling serves to establish the technique, and it is then adopted in other parts of the organization. In such cases, the categories used in the first study should be considered carefully as a means of setting up comparisons across organizational divisions. Methodology should be kept consistent, but no other special instructions are necessary for broadening the use of Work Sampling.

Since the overriding consideration in most Work Sampling programs is improvement of the work situation under study, a review and evaluation of the initial Work Sampling data quite frequently leads to a decision that observations should be continued, or that future studies are necessary. Such decisions may be reached as a result of one or more of the following:

1. Supervision has become aware of the usefulness of Work Sampling as a technique for the continuous measurement of shop operations.

In this case, where it is desired to continue Work Sampling as an aid to supervision, the initial study must be examined carefully. It may be that categories should be combined, that the time rate of observations should be altered, or that the degree of detail required should be changed. Note that some of these changes may be in the direction of simplicity, and some in the direction of greater complexity. The criterion here should be the proved needs of the supervisor. The only caution necessary is that where possible the changes should allow the first study to be used for comparison with future studies.

The supervisor usually is most interested in detecting changes *in time to act,* and at the same time he would like some means of reporting a *lack* of change, if that is the existing condition. For these purposes, use of the Chart for Category Proportions is invaluable. Such a chart provides a sensitive indicator of change, and at the same time introduces the super-

visor to basic concepts in statistics which will be of value in other phases of supervisory work.

While use of the Chart for Category Proportions is not intended to be limited to supervision, a special point is made that the supervisor is the person best situated to take immediate action if operating conditions require such action. The Control Chart concept is, of course, useful at all levels as a self-reporting indicator of trends or of erratic performance.

2. Management institutes change, and plans future studies to appraise the effect of such change.

In this case, Work Sampling may be discontinued for a period of time sufficient to allow the changes made to take effect, and a separate Work Sampling study is then made. When such a "check" study is made, the results are tested for significance of difference of $\bar{p}$, to determine whether or not the desired change has taken place. This presupposes that the change will be reflected in the proportions of time spent in specific categories.

Details of performing the check study should be similar to those in the initial study, in order to make comparison valid. The advantage of the check study over continuous collection of observations throughout the change is that fewer observations may be necessary. The disadvantage is that a continuous study will indicate the trend of improvement, and enable proved Control Chart techniques to be used.

3. It is decided to investigate the nature and extent of yearly or other long-term cycles.

In these cases, a company may be aware of certain seasonal or long-term cyclical variations in its business. For example, if the initial Work Sampling study has been taken during an "average" month, it may be desired to take supplemental spot studies of a "busy" month and of a "slow" month. While this is sound practice, an even better solution might be to take a

series of shorter studies, perhaps one every month. In this way a better concept of the entire cycle could be gained, and the Control Chart technique could be applied.

While the above uses are quite common, they are by no means definitive of all the follow-up methods used to exploit Work Sampling. Once the technique has been established and an appreciation gained of the Control Chart and significance of difference of $\bar{p}$ tests, Work Sampling becomes a very versatile tool. It is quite literally true that only the imagination limits the uses to which Work Sampling has been put in appropriate work situations. Reference to the Bibliography is adequate proof of this point.

To summarize, it is usually advisable to follow the initial Work Sampling study either with a continuation of observations or with a separate series of similar studies. This is true because of the ability of the technique to reflect stability or trends of activity and to determine the presence or absence of change. Most management activity is directed toward control and improvement. The statistical techniques outlined in previous chapters, when used to analyze Work Sampling data, provide management with the tools to exercise control and to measure improvement or change. Most change takes place over a period of time; for that reason Work Sampling must be extended to encompass this time.

10

Selling Work Sampling to Others

Why Is It Necessary to Sell Work Sampling?

No apology should be necessary for the use of the word "selling." The hard fact of business and industrial life is that many worthwhile endeavors have failed because they were not presented aggressively and in a positive manner. Many executives actively cultivate the practice of placing the burden of proof on those who propose change. This is healthy, unless carried to extremes. For if a new technique, such as Work Sampling, is worthwhile and applicable to a particular situation, certainly it can be presented as an attractive alternative of management action.

The word "alternative" is used above because it must never be forgotten that most managements feel that *not* to change may itself be a very reasonable course of action. A prudent management's natural desire for thorough appraisal of new techniques must not be dismissed as that old reliable whipping boy, "human resistance to change." Rather, opportunity should be sought to prepare an honest and complete presentation of Work Sampling as it is intended to be applied, and management's appraisal should be solicited on this basis.

Ultimately, the success of the study will depend upon the support of management, and the cooperation of *all* who are involved in the study. This support and cooperation must be

promoted by a form of selling. It does not exist prior to the study, and yet it is vital to success. There is nothing unusual about the need for selling. Every company sells its products, individuals sell their ideas, and management sells other employees the concepts of systematic operation and improvement. Indeed, to institute Work Sampling *without* an honest attempt to sell its merit to all concerned would be negligent in the extreme, and would minimize the worth of the technique, and the probability of successful application.

Who Are Others?

Everyone concerned with a Work Sampling study is entitled to a clear explanation of the technique. Management, supervision, union officials, and those being observed all have a stake in the proper conduct of Work Sampling. The degree of detail discussed, the extent to which statistical theory is explored, and the manner of discussion will vary from group to group. However, all discussion should be consistent, and all questions concerning technique should be answered to the satisfaction of the personnel involved.

No one is so naïve as to expect immediate and enthusiastic acceptance of *any* analysis or measurement technique by everyone concerned. On the other hand, honest objections must be considered. Once a decision is reached to go ahead with a Work Sampling study, every effort should be made to do the job properly. It is to be expected that some misgivings will be present at the start of the study. It is the task of those conducting the study to overcome such skepticism in the course of the study. Given a fair trial, Work Sampling has in the past proved to be a technique which makes "believers" out of skeptics. But to obtain this fair trial, Work Sampling usually must first be sold to *all* concerned.

A Few Words of Caution

Work Sampling is an objective analysis and measurement technique which offers unique advantages through its use *in the proper situations*. But it should not be used indiscriminately. It is better to start with a limited application under favorable conditions than to attempt sweeping coverage without adequate experience or manpower. Acceptance will be gained through satisfactory results. Therefore the first study particularly should be done with extreme care, and objectives set which not only demonstrate the unique advantages of Work Sampling, but which can be met in a satisfactory manner.

As a corollary to the above, do not try to make Work Sampling "all things to all men." Work Sampling has proved to be quite versatile, but is best suited for the uses given in previous chapters. While Work Sampling can be used for highly repetitive tasks, it probably is not as suitable as the *sole* analysis and measurement tool for such jobs as other work measurement techniques. There are, however, many situations in most companies for which Work Sampling is uniquely suitable; do not make the mistake of distorting the basic simplicity of Work Sampling in order to provide coverage in any and all tasks. No technique can do this.

The previous paragraphs really are introductory to the following basic caution: Work Sampling is a sound technique which has many inherent advantages. There is no need to oversell it by making extravagant claims. Management and employee alike have had enough experience with work analysis and measurement to know that if there were a quick and easy solution to their particular problem it would long since have been discovered. Therefore, emphasis should be placed on the gains *uniquely* possible through Work Sampling. No apology need be made for the fact that to be effective Work Sampling must be done properly, and must be supported. Man-

agement already knows that "you can't get something for nothing." The selling job consists of presenting Work Sampling in its proper light, so that management can make an intelligent decision pertaining to its use.

How to Sell Work Sampling

We know that each of us is guided by his own experiences, and by his present job demands. It follows that every person concerned will examine and appraise Work Sampling in a slightly different light. The general manager and the foreman both may ask, "What's in it for me?" The type of answer that each seeks will be different, however, because the demands of their daily work are different.

It is up to the director of the study to discover the needs which a Work Sampling study might fill. He then must sell each group on the desirability *to that group*, and to the company as a whole, of Work Sampling. The biggest single aid to this selling is the ability to communicate ideas. Such communication must be done in an orderly fashion, and will require work.

Consider for a moment the mental state of a supervisor when first confronted with a proposal that he participate in a Work Sampling study. His first reaction takes the form of a question, Why? His next reaction is another question, What is Work Sampling? Therefore, the first step in *selling* Work Sampling, like the first step in *doing* Work Sampling, concerns the objectives to be sought.

To take things in order, management will have to be sold first of all. Since the need for the study usually originates with management, the preceding discussion should suffice as a guide to the business of gaining management acceptance. In the case of the supervisor and foreman, the objectives can best be explained by higher line supervision. This might be

done as an introduction to explanation by the director of the study. In brief, the foreman or supervisor wants to be assured that *his* boss supports the study and that the objectives are practical.

The setting of specific objectives has been discussed. But while all groups may be aware of the general need for, say, cost control, the actions taken by each group to achieve this will differ. Also, top management needs information in a different form and degree of detail than does line supervision. Finally, the personal participation required of each group will vary. Therefore the objective "improve cost control" must be translated into a series of particular reasons *why* this is desirable, and how a Work Sampling study will help.

Once the "Why?" has been answered by management, the director of the study should undertake the explanation of "What is Work Sampling?" The exact approach here will vary. In general, the organization of material of this book may be followed, tailored to fit the situation. The following suggestions may be of value:

1. Be sure that your presentation is logically arranged and that new expressions are explained as they are introduced.
2. Prepare each session for the particular group involved.
3. Going back to the objectives previously explained by supervision, show where the data obtained in the study will be of value to management and employee.
4. Relate general case given in text to the particular application under discussion.
5. Emphasize the flexibility of category definition and the selection of observers and pattern of rounds of observation. Work Sampling has many "do-it-yourself" aspects.
6. Prepare visual aids and notes appropriate to the group.
7. Secure management's agreement to hold uninterrupted

sessions of instruction. The few hours' training time should not be broken into by odd calls for the participants.

8. Emphasize the economic balance between information obtained and time spent in study.

9. In brief, show the fact-finding nature of Work Sampling. This aspect, rather than traditional time-study approach, has proved to be most attractive. No matter what the preconceived ideas of work measurement, everyone prefers to operate from facts.

10. Consider it essential that questions be welcomed, and try to obtain participation in deciding upon the details of the study.

11. Always keep in mind that the success of the study depends upon the quality of the initial observations. This in turn depends upon the motivation and proper instruction of the observers.

11

Case Study A: Office Activity in Preparation for Data Processing

Statement of the Problem

A medium-sized soft-goods manufacturing concern was planning to introduce an electronic computer and mechanized data processing to its entire paper-work system. Management sought a reduction in clerical cost, more rapid flow and better availability of information, and better sales and production information.

As a first step, the present system was analyzed, starting with the order and billing department, which received all sales orders and controlled the finished goods inventory. This case problem describes the Work Sampling study made in the order and billing department. The formal report issued at the conclusion of the study is used here in its entirety, and supplemental exhibits are included to supply necessary detail. Since this was the first Work Sampling study done in the company, the formal report was originally written to serve as a guide for other supervisors in the conduct of succeeding studies.

Twenty-one employees were studied. All personnel were located in the same large office, and all work positions were easily visible from the desks of the supervisor and his assistants.

M E M O

April 29, 1955

TO: ALL PERSONNEL OF THE ORDER & BILLING DEPARTMENT

WE NEED YOUR HELP!

At the present time the company has commissioned Mr. Heiland and Mr. Richardson both Professors of Industrial Engineering at Lehigh University to make a study of the company operation. These men teach a full load at Lehigh then work a day or so in at the plant.

The question asked these men by management is in part "Can we utilize any of the Electronic advances in our company?"

To boil this down they are studying the possibilities of the use of a "Univac". The "Univac" is an electronic computing machine which has a memory where many figures may be stored. The study is being made in order to be able to advise the company whether or not the large expenditure for one of these electronic marvels is justifiable.

This brings us down to our small part. In addition to the information you gathered on the number of rolls by color and width sold since January 1953, they want us to participate in a "Work Sampling Study". First let me belay any fear that this is on a personal basis. IT IS NOT! Let us define Work Sampling for you:

"Work Sampling can be used in an office for the quantitative analysis, in terms of time, of the activity of people, equipment or any other observable state or condition". This is a mouth full and actually means that it is a study to find the Peaks and the Lows in the work flow.

The actual study is made by taking eight Random observations each day of activity of the department. "Randomness" is the statistical sampling of conditions at any given instant of time. The actual observations will be taken by myself, Bob or Al, no outsiders. We will then break the conditions into the following:

Fig. 11-1

Writing Operations
Handle Papers
Operating Office Equipment
Telephone
Conversation
Filing
Walking
Absent
Absentee
Other non-working

After a period of time which is set by the men of Lehigh, the observations are summarized and compiled into a chart used to compare working habits of this company with others in industry both actual and theoretical.

Any questions you have please ask them and we will try to give you an answer or get you one.

Thanks,

John J. Patterson
Order & Billing Dept.

JJP/dh

FIG. 11-1 (*Continued*)

There was no union in the office. Management gave strong and continued support to the program. The supervisor and his assistant acted as observers. The director of the study was an assistant controller who had been with the company for 11 years. His background was in accounting and manufacturing records. He had no college work in statistics. He was regarded as a most promising employee and was respected by his fellow workers. He had available the services of consultants who had been brought into the company to help in the over-all installation of the new system.

The study was announced to the order and billing department personnel orally, and also through a memorandum (Fig. 11-1). No adverse reaction was experienced. The observation sheet used in the study is shown in Fig. 11-2. A control chart used to check randomness of observation times is shown

in Fig. 11-3. Other details of the study are contained in the formal report of Work Sampling in order and billing department, which follows. This report is given in the form in which it was presented to management.

DATE 5/6/55

OBSERVER

DEPARTMENT

REMARKS: 6

ACTIVITY KEY

1 Writing operation
2 Handle papers
3 Operate office eqpt
4 Conversation
5 Filing
6 Walking
7 Absent
7A Absentee
8 Other nonworking
T Use telephone
– In any group

ASSIGNED DUTIES Key

(1) Control clerk
(2) Stock records
(3) Customer corr.
(4) Filing clerk
(5) Teletype
(6) Secretary
(7) Invoice clerk
(8) Checker
(9) Recap. clerk
(10) Auto opt. clerk
(11) Stenographer

NAME	Assgn. duty	*		*		*	T	*	I	*	M	*	E	*		*	
		8	27	9	56	10	20	11	48	1	58	2	08	3	45	4	04
Reeder	1		4		6		2		2		T4		3		2		2
Harper	6		1		4	8	2		7		1		1		5		5
Zeigler	7		1		1		1		7		1		5		1		1
Muse	7		3		3		2		8		3		3		7		2
Matthews	7		1		1		2		2		1		1		1		2
Heishman	7		1		1		1		4		2		1		1		7
Mullen	8		4		2		2		2		3		4		3		2
Ditzel	9		4		3		6		2		2		1		2		1
Bream	10		6		1		1		7		1		7		7		2

*Job actually on at time of check.

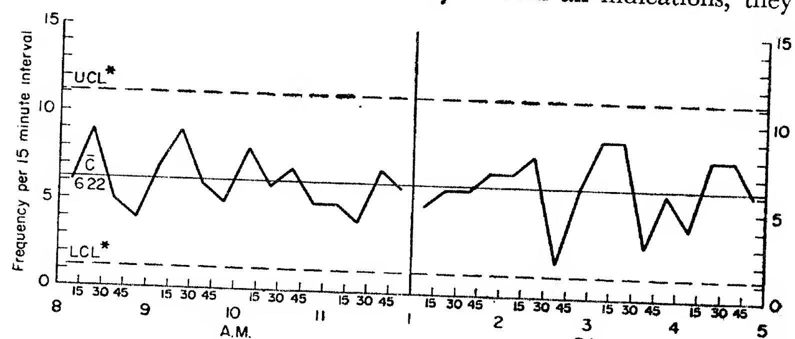
FIG. 11-2. Work Sampling observation sheet.

WORK SAMPLING IN ORDER AND BILLING

During the month of May, and again for a week during June, a work sampling study was made of the Order and Billing Department. May was considered to be a typical month, and the third week of June (just before the Chicago Show) was considered to be a "slack" period. In addition, a one week's check study will be taken in August, at a time generally considered to be a "busy" period.

Thus, we hope to establish the "usual" distribution of time required to do the job, and also to check the extremes. Since Order and Billing should follow the semi-annual pattern of our business, it is realized that there will be "slack", "usual" and "busy" periods; the work sampling should establish the nature and extent of the work-load variations.

At the outset, it should be stated that the Order and Billing Department employees should be congratulated for the interest which they have shown in the study. From all indications, they



* Control limits set at $\bar{c} \pm 2\sqrt{\bar{c}}$, or 95 per cent confidence interval

FIG. 11-3. Control Chart used to check randomness of Work Sampling study in order and billing department, April 29 to June 17, 1955.

$$\bar{c} = \frac{199 \text{ rounds of observations}}{32 \text{ intervals of 15 minutes}} = 6.22$$

Total man-observations = 199 × 21 people = 4,179

Conclusion: Equivalent and representative coverage of entire workday.

have cooperated very well. This is particularly true of the supervisors, who also acted as observers.

The purpose of this report is to review the results of the study, and to formalize the procedure for future reference. Therefore, the entire procedure will be broken down into the necessary steps; these can be used as a guide for check studies, and for studies in other parts of the organization.

I. Objective—The objective of this work sampling study was to determine the proportions of time doing specific types of work by the various members of the Order & Billing Department. Put another way, the objective was to classify all work done into broad, simple categories such as writing, handling papers, etc., and to identify with each job the specific pattern of activity necessary to perform

the job. The ultimate objective was to prepare for the introduction of a high-speed electronic computer.

General Comment—The need for a meeting of the minds among supervision, observers, and management prior to work sampling is obvious. In future studies, be certain to come to an understanding of objective before you do anything else.

II. Specific planned uses—

1. To help establish the nature of the work done in Order and Billing. This is important, because there are many things a machine cannot do, such as take an order over the phone, exercise judgment in the allocation of stock, or, in general, think.

2. To help the supervisors; first, by giving them a means of getting fairly precise information concerning work activity, and second, to accustom them to thinking in terms of the law of large numbers. This last will be of particular importance with the advent of any computer.

3. To determine the nature and extent of cyclic or peak load conditions, as reflected in observable activity. This already has been covered in discussion, but the fact remains that every office is subject to work load fluctuations, absenteeism, vacations, special jobs, etc. Thus, most offices have a cyclic condition, and the office force meets peak loads by working harder. As a corollary, most offices simply relax slightly when the work load drops. This is to be expected, and is quite normal. But for planning and supervision, the nature and extent of the cycle should be known.

4. To aid in economic analysis of equipment needs. This particularly applies to the substitution of a file of punch cards as an adjunct to the use of the computer.

General Comment—These uses are presented in the order in which the information will become available; as we obtain more observations, we gain greater reliability.

III. Designation of Categories of Activity—In Order and Billing, it was decided to separate the work into categories as follows:

1. Writing operation
2. Handle papers
3. Operate office equipment
4. Conversation
5. Filing
6. Walking
7. Absent 7a. Absentee
8. Other (Nonworking)

T—Use Telephone

It was felt that these categories would provide the information considered necessary to meet the objective. Further, these met the general requirements in that they were (a) Easily recognizable by sight (b) Capable of fairly precise definition, and (c) Consistent with the end use of the study. By this last is meant that categories of activity could be matched with the performance of specific jobs.

In addition to the categories of activity, a list was made of "assigned duties," which enabled the observer to identify specific jobs, even though, because of absenteeism, work load variations, etc., the personnel on the jobs might shift around. This list of "assigned duties" was as follows:

1. Control Clerk
2. Stock Records
3. Customer Correspondence
4. Filing Clerk
5. Teletype
6. Secretary
7. Invoice Clerk
8. Checker
9. Recap Clerk
10. Auto Stock Clerk
11. Stenographer

IV. Selection and Training of Observers—This proved to be a relatively simple step. The Supervisor and Assistant Supervisor acted as observers. They were extremely familiar with the activity, were in a good physical location to make observations, and most important, were willing to undertake the job and had the intellectual curiosity to try something new. The objectives, theory, and possible pitfalls were outlined to them, and two afternoons were spent in going over the methodology. In addition, someone experienced in Work Sampling "looked over their shoulders" while the study was in progress.

V. Announcement of work sampling program—Here an outstanding job was done. The announcement (attached) took the form of an open letter to the Order and Billing Department, and every effort seems to have been made to be as open and honest as possible. Whether a written announcement is made, or verbal notification is considered enough, it must be emphasized that the people being observed should be informed.

VI. Design of Forms—

(a) The observation sheet (appended) is an example of one of the forms necessary. The particular arrangement is not necessarily

standard. Number of categories, number of persons or machines observed, etc., will influence design. If punched cards are to be used, or if observations are to be punched later, this too must be considered.

(b) Summary Sheet (enclosed)—Any convenient means of summarizing data, by function, category, etc., will do.

(c) Graphs of results—These are extremely helpful in presenting results, and will be discussed later under "results."

VII. Randomization of Times—It is of extreme importance that the times of observation be random. "Randomness" means, simply, that there is no apparent order to the times, that each individual minute has an equal chance of selection as the time of observation as any other minute, and that the entire period desired to be covered *is* covered. In this case, it was decided to make one observation per hour. A table of random numbers was used, and numbers between 00 and 59 (inclusive), were selected as they occurred. Thus, if the numbers in the table were 923640719, etc., the first observation would be made at 8:23, the second at 9:40, the third at 10:19, and so forth. It might be added that in the mill only five observations per day were made, and thus, three digit selections were made.

By randomizing times, a systematic error (such as would occur if observations were taken "on the hour") is avoided. By taking a large number of readings, it is possible to cover the entire cycle, and thus minimize errors inherent in any sampling procedure.

VIII. Making Observations—All that was required of the observer (supervisor, in this case) was that he be conscientious in making observations at the random times selected, and that he classify into the proper category whatever activity he observed *at the instant of observation*. The observer did not try to anticipate or "second guess" activity. If he missed a round, or was late, he noted this on the sheet. Care was taken to indicate absentees, etc., so that the study could be used with confidence.

IX. Results—The best way to discuss the results of a work sampling study is to go back to the objectives of the study, and appraise the extent to which these have been met.

(a) To establish the nature of the work done in Order and Billing: This is shown graphically in the large chart labeled "Distribution of Work Sampling Observations." In total, the time distribution was as follows:

Writing	26.5%
Handle Papers	39.6%
Operate office equipment	4.4%
Conversation	10.6%
Filing	5.9%
Walking	4.1%
Absent & Other (not work)	8.9%

The overall only serves to indicate that the personnel in the department are conscientious, and that the supervision is capable. The chart shows distribution of activity by groups, and is therefore the most meaningful form of presentation.

In general, the work sampling supported the subjective opinions held by the supervisors. The supervisors found no obvious errors or discrepancies. But for purposes of comparison at a later date, and because the study "put a number" on the proportions of activity, the study is valuable. Now the supervisors know (quite precisely in the major categories) just *how much* of each activity occurs. This makes possible planning and will provide a bench mark to guide methods improvement.

(b) To determine the nature and extent of peak load or cyclic conditions—This was done by charting the data by groups by per cent of each category, along a time axis. Examination of the charts will reveal the fluctuations in categories. The supervisors were able to draw meaningful conclusions from these charts, which will not be dealt with here. It is sufficient to say that an expected drop in useful activity did not materialize during the normally "slack" period selected for a spot check, that some slight cyclic trend seems apparent, and that the present policy of paying spot overtime seems justified in preference to hiring a new employee.

(c) To aid in economic analysis of equipment needs—For this purpose the study revealed the *possible* gains in each area. For instance, all walking consumed only 4.1% of the time and all "operate office equipment" consumed 4.4% of the time. While this is by no means indicative of the overall importance of these activities, it seems obvious that if we could cut "operate office equipment" and "walking" time in half through a different office

layout and newer equipment, we still would save only about 4% of the total time. On the other hand, if we reduced "handle papers" by only ten per cent, we would achieve about the same savings. Thus the study concentrates attention first on the areas of greatest potential saving. Most important, we can now appraise improvements in terms of dollars and cents.

Reliability of study—Without going into too much detail, we can be sure, 95% of the time, that the overall "handle papers" proportion of time will be between 38% and 41.3%, provided no change has occurred in the office. This high reliability is due to the fact that a total of 3,810 observations were taken. For the individual

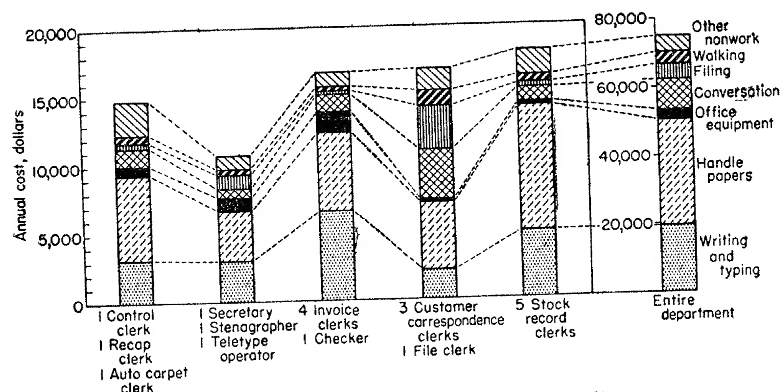


FIG. 11-4. Order and billing department Work Sampling summary.

groups, which make up the total, a lower reliability will be found. Hence, the more observations the better, up to an economic limit of reliability.

There is no need here to go into the mathematics of statistics, for the burden of calculation should not be placed on the supervisor. It is, however, important to remember that results depend upon the number of observations and the conscientiousness of the observer.

In conclusion, it is felt that no great burden was placed on the supervisors, that the results will be most useful, and that the technique of Work Sampling is straightforward in use, provided the proper attention is given to the details, and the observations made in a conscientious manner.

Results

This study revealed the amounts of time spent by various employees in each of the activities. These are given in the table of the report, and also in Fig. 11-4. From the study, alternate cost figures could be developed. Planning for the transfer to punched cards was made effective, and a smooth transfer was made. Cost estimates proved to be accurate.

A follow-up study showed that the seasonal cyclic effect was of much less importance than had been supposed.

The Work Sampling study in order and billing was considered to have met management's objectives. To generalize, the problem of preparation for the introduction of mechanical data processing should be preceded by a sound analysis of system, personnel, and cost requirements. In clerical work particularly, Work Sampling has proved to be an effective means of work measurement for this purpose.

12

Case Study B: Engineering Design and Drafting

Statement of the Problem

A large engineering design section, in the chemical-petroleum type industry, was studied. This section was responsible for the design of process, equipment, buildings, piping, and electrical and structural-steel work. The design was carried through to the blueprint stage. Approximately two hundred designers and draftsmen were employed in the section.

The designers and draftsmen were organized into groups on a functional basis, as indicated in the discussion which follows. These groups were located in seven different offices in four different buildings. It was felt that this separation led to excessive visiting and travel time. A central file and blueprint facility was in use. An appraisal of this arrangement was desired.

The fundamental problem facing management was that the work load was increasing and that experienced designer-engineers were difficult to recruit. A number of alternative solutions were under consideration. Management suffered from the lack of specific knowledge of the activities performed by the designer-engineers, in terms of time. Among other things, it was desired to secure some measure of the following:

1. Time spent by various designers in groups other than their own
2. Time spent in sketching and planning work
3. Time spent in routine detailing and drawing
4. Time spent in discussion and consulting
5. Need for blueprints and blueprint service

Background of Problem

For a number of years the company had been doing all its own design work. The forecast was for increased volume, but the type of work was changing to require more special skills. The company had been considering the alternative of "letting out" some design work to an outside design firm. It also had the alternative of requesting more design work from various vendors. The long-range solution to the dispersion of the present design force was considered to be a new building. But this was at least two years away.

The design section was organized into 12 groups. As shown on the summary chart of observations, the groups varied in size and in function. The chief draftsman had organizational and administrative responsibility for all groups. The groups were as follows:

Architectural—4 men
Equipment—9 men
Instrumentation—6 men
Electrical—26 men
Piping—Four groups of 15, 29, 20, and 12 men
Structural steel—Four groups of 8, 13, 9, and 6 men

Each of these groups was headed by a supervisor, or group leader. The larger groups had assistant group leaders. The only measure of production was square feet of blueprints produced by each group.

Why Work Sampling Was Used

The fundamental reason for the use of Work Sampling was that management felt that in dealing with a group of salaried men of technical background, time study or predetermined work times might result in unfavorable personnel relations. In addition, since thinking and creativity were involved at least in part, the conventional "unit-of-work" approach of these techniques was not felt to be suitable.

Work Sampling by group supervisors would at least ensure acceptance of results by these supervisors. The expense would be quite small, and such a study would give management some frame of reference to help in making a choice among the alternatives. Management's objectives were first, to measure observable activity for immediate decision, and second, to seek concrete indications of possibilities for improvement of the present situation.

Finally, there was *no* generally accepted means of measurement of design work. The common attitude was that the work was not capable of being measured by other than subjective means. The chief draftsman felt that while this might be true for that part of the men's activity which involved creative thinking, it was not necessarily true of the actual mechanical work connected with design and drafting activity. He felt that no harm could be done, and could see possibility of gain. While this seems to be a weak statement of purpose, it must be remembered that Work Sampling was new to the section and that no work measurement had ever been attempted there prior to the study.

Organization for Work Sampling

The responsible top management of the section had instituted plans for the study, and had displayed an active interest throughout. Weekly reports were given them, and the chief

draftsman let it be known that he personally was much interested in the results.

The director of the study was an office methods analyst who had been working with the section for several months. He had a business degree, and four years' company experience. He was familiar with Work Sampling through a company training program which occasionally employed outside consultants to train in special techniques. One such training program had covered Work Sampling. This was the first study he had supervised, although he had assisted in one large-scale study for the parent company.

Group leaders agreed to act as observers. This was done because the extra expense of special observers was undesirable and because the chief draftsman felt that better acceptance would be gained in the drawing rooms if the men observed were familiar with the observers.

In the discussion with the group leaders, it was brought out that the group leaders felt that the purposes of the study did not require that individuals be identified by name. They said that the men would accept the study better if it could be pointed out that no individual *could* be penalized as a result of the study. There was no objection to this, and a code was used rather than names. The group leaders alone knew the code.

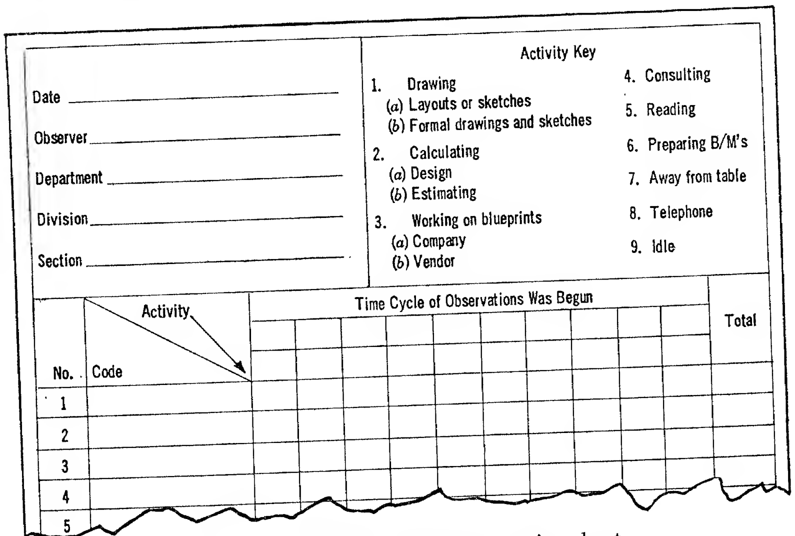
Selection of Categories

The categories were selected at conferences of the group leaders, the director, and the chief draftsman. These categories are shown on the observation sheet (Fig. 12-1). Only three of these need special comment. The others seem self-explanatory.

Category 4, Consulting, was defined as "two or more of the men of the same group talking together, no matter what the subject of conversation seemed to be." While some thought

that it would be "obvious" if baseball rather than design was the subject of conversation, it was felt that a more objective and reliable set of data would be obtained by treating all conversation the same way. If the group leaders desired to exercise any subjective judgments, this should be done independently of the study categorization.

Category 7, Away from Table, was defined as "not at table, not in group; if a man is consulting in another group he shall



Date

Observer

Department

Division

Section

Activity Key

1. Drawing
   (a) Layouts or sketches
   (b) Formal drawings and sketches
2. Calculating
   (a) Design
   (b) Estimating
3. Working on blueprints
   (a) Company
   (b) Vendor
4. Consulting
5. Reading
6. Preparing B/M's
7. Away from table
8. Telephone
9. Idle

No.	Activity / Code	Time Cycle of Observations Was Begun										Total
1												
2												
3												
4												
5												

Fig. 12-1. Work Sampling observation sheet.

be classified as away from table. This category also might include personal visits and all other causes of absence." The point here is that subjective evaluations such as "necessary absence" were avoided. While some detail was lost, the readings were consistent.

The title of category 9, namely, Idle, was poorly chosen. No group leader wanted to state that a man was Idle. This represents a mistake in procedure, and resulted in a small human relations problem. By the time it was discovered, it was too late to change, in the opinion of the director.

Mechanics of Work Sampling

The procedures used to perform the Work Sampling were quite straightforward. The group leaders were trained, the study was announced, times were randomized, and seven or eight observations per man per day were taken. No observations were taken during the scheduled coffee breaks.

Because of the fact that the first three categories (Drawing, Calculating, and Blueprint Work) required more detailed information than could be gathered at a glance from the group leader's desk, a unique method of observation was used. The group leader made the initial categorization of activity from his desk. This would be, for example, Drawing. Then, after he had finished his round of observations he would visit the desks of men who had been observed in one of the first three categories and gather the additional information. Since the basic categorization had been established, the men welcomed rather than resented such visits. There was general comment that the study forced group leaders to communicate more with their men and to become more aware of the work each man did. Both felt that this was desirable, in that it bettered communication, and made the study seem less mysterious.

Results

The results of the study are shown in Table 12-1 on analysis of Work Sampling percentages by categories. In addition, it was found that no significant differences existed from week to week in the major categories. The study was done for a period of three weeks. No cycle was evident. It was quite probable that a seasonal cycle existed, but management was willing to accept the relatively short three-week study. Observation times were tested and found to be random.

The most significant items of information gathered from the study were as follows:

TABLE 12-1. ANALYSIS OF WORK SAMPLING—PERCENTAGES BY CATEGORIES

Group number	1	2	3	4	5	6	7	8	9	10	11	12
Function	A	E	I	El	P	P	P	P	S	S	S	S
No. of men in group	4	9	6	26	15	29	20	12	8	13	9	6
Category:												
1. Drawing												
(*a*) Layout or sketch	12.5	7.4	80.4	9.6	2.6	13.2	3.4	6.5	1.3	3.1	1.0	9.3
(*b*) Formal drawing	22.5	39.8	2.8	40.0	49.0	35.9	37.6	31.7	48.2	43.3	30.4	22.9
2. Calculating												
(*a*) Design	....	4.6	....	1.2	4.4	1.7	0.3	.....	7.4	13.2	4.8	12.7
(*b*) Estimating	0.5	....	....	.....	0.1	.....	1.1	.....	1.0	0.3		
3. Blueprint work												
(*a*) Company	7.9	3.8	....	3.4	9.5	15.2	26.2	3.7	2.4	13.5	25.0	24.7
(*b*) Supplier (vendor)	1.0	4.1	....	1.1	1.0	1.1	0.7	0.2	3.6	1.6	4.6	2.3
4. Consulting	24.6	21.5	1.2	26.7	19.7	17.2	16.7	20.7	17.3	10.6	29.3	13.5
5. Reading and reference	6.4	4.4	0.3	5.1	1.6	2.4	1.4	2.3	5.8	2.6	0.5	2.2
6. Preparing bills of material	....	....	....	1.3	.....	.....	1.0	.....	0.7	0.1		
7. Away from table	19.7	9.5	13.1	5.3	7.2	8.0	8.4	10.8	7.9	8.5	4.1	7.7
8. Telephone	2.3	1.6	2.2	1.4	1.0	0.6	1.0	2.0	0.8	0.3	0.2	0.5
9. Idle	2.6	3.3	....	4.8	3.9	4.6	2.2	22.1	3.5	2.8	....	4.1
No. of observations Total—15,735	391	892	650	2,485	1,549	3,041	2,000	1,074	825	1,340	930	558

1. Approximately 40 per cent of the time of the piping and structural groups was spent in formal drawing or sketching.

Comment: A large part of this could be done by less skilled personnel.

2. Approximately 30 per cent of the time of all groups was spent in conversation or away from the table.

Comment: Reorganization into composite groups might reduce this figure substantially.

3. Relatively a small amount (2.0 per cent) of the time was spent working on supplier or vendor prints.

Comment: It had been thought that this was much higher.

4. Very little reading or reference work was done.

Comment: Several duplicate sets of reference books were maintained at some expense. It seemed that some of these could be eliminated.

Action Taken and Final Appraisal

As a result of the study, management reorganized the section into composite groups, to reduce travel to specialist groups. Also, semiskilled personnel were hired to do much of the rou-

Fig. 12-2. Work Sampling study. Piping and structural group—piping.

tine drawing. This enabled the section to increase its output without hiring new and "hard-to-get" designer-engineers. A better system of supplying and coding blueprints was devised.

At the end of six months, it was estimated that the above changes had saved $100,000 over the cost of expanding the design section, or subcontracting for the increased design

load. No personnel difficulties were experienced in the reorganization.

In appraising the study, it must be kept in mind that this was the first use of Work Sampling in the section, and the first instance of formal measurement of design activity with which the participants were familiar. Still, management felt that its objectives had been achieved.

There were a few instances of poor technique in the conduct of the study. These were:

1. Use of Idle as a category. This has been discussed, but it did lead to a few questionable results.

2. No measures of production were considered practical. A program for evaluating complexity of work was undertaken, but was not used in the study. Subjective opinion was relied upon.

13

Case Study C: Plant Maintenance and Construction

The Problem

One of America's largest manufacturers of hard-surfaced floor covering, including linoleum, tile, and corkboard, used Work Sampling to obtain a better grasp of a very old and difficult problem: How effective and efficient is our maintenance and construction work?

As in many other process and semiprocess industries, this company noted with mixed feelings the tendency of maintenance costs to become larger and larger in proportion to direct-labor cost, as more and more mechanized and automatic processes and improvements were made. It seemed as though an improvement in direct-labor cost through increased efficiency, usually through more complex equipment, had the effect of adding one more skilled mechanic for each reduction of six to ten direct-labor (production) employees. Since mechanics' wages were, and are, substantially higher than unskilled direct-labor employees, the effect seemed to be to rob the improvement of a substantial share of its nominal saving.

There is no question that the savings involved in mechanizing and automating processes are sufficiently high to more than cover the increase in maintenance costs. But in the absence of measured day-work standards, the management has little pro-

tection against a creeping increase in time loss, increasing difficulty of supervision in planning, and general burgeoning of all costs incidental to maintenance.

In addition to this factor, there was and is the problem of control of costs in major construction work, which in this plant is done almost exclusively by the company's own construction workers. In many cases, since both maintenance and construction work are done by the same mechanics at different times, much poor planning and resulting high costs can result.

The major problem here was the difficulty in estimating or determining *exactly how the mechanics' time was being spent.* At first blush, this may seem to be simply a matter of reviewing time cards and cost reports, but most management and nearly all industrial engineers who have ever had much contact with this problem are aware that time cards do not tell this story! This is true for a number of reasons, not the least of which is the sheer inability of any human intellect to grasp the problem of planning and directing the work of some 600 mechanics, as in this case study.

Maintenance personnel usually differ from most manufacturing personnel in two important respects:

1. They are better trained, possess higher skills, and higher intelligence.

2. They are accustomed to a larger measure of independence and self-discipline and, usually, less supervision.

Because of these differences, the problems of planning and control are frequently not so complex as they may appear. However, it is also true that there is great difficulty in *evaluating* just how well planned, supervised, and controlled the work really is, and in getting a grip on the actual cost-saving potential inherent in it.

In this plant, there are in excess of 30 acres of floor space, and about 3,000 employees, of whom about 600 are mechanics.

Counting routine repetitive types of maintenance work, about 4,000 maintenance and construction assignments are made *per week!*

The maintenance and construction department is under a superintendent who reports to the chief engineer. There are about 30 foremen, reporting to 6 general foremen, who in turn report to the superintendent. About 400 of the 600 men are employed in relatively fixed locations, while about 200 are roving mechanics, involved in repairs, construction, and similar types of work.

For about 20 years, there has been an industrial engineering staff attached to the superintendent of maintenance and construction. During the 1920s and early 1930s, an incentive plan based on Barth slide rules was used in machine-shop work, but was abandoned because of its extremely high administrative costs in relation to its contribution to cost saving. No incentive plan has been proposed since that time, and none is likely to be proposed.

Why Work Sampling Was Used

In mid-1954, the management decided to undertake a critical examination of its maintenance and construction costs, to be followed by a long-term (two to five years) program to institute any improvements indicated, and eventually, measured day work.

A brilliant industrial engineer was placed in charge of that function within the maintenance and construction department, and he was convinced that the objectives were valid and attainable. He himself was a journeyman machinist, was well known and highly regarded by both the management and the shop mechanics, and he was permitted to reinforce his staff with several good young engineers chosen for the pioneering type of spirit so necessary for the success of such a huge venture.

A survey of then-present conditions and efficiency was the first step, since management desired a detailed proposal before entering upon a long-range program. It was here that Work Sampling was used for the first time in this company.

Work Sampling was first used, and has continued to be used, only as a mechanism that enables a convenient, economical evaluation to be made of *over-all time utilization*, and has not in itself been used as a means of appraisal of *pace* during actual work. Work Sampling was selected as the time-utilization yardstick for the following reasons:

1. Its relative economy of application, as compared with production studies, subjective evaluation, or self-reporting.

2. Its promise as a tool with which to obtain "team effort" through having line supervisors make the preliminary appraisal.

3. Its ability to enable a line foreman to take an enforced, searching, objective look at what his own men and equipment were doing.

4. Provision of a regular topic for review by general foremen and superintendent, in conferences with foremen.

5. Opportunity for foremen to put teeth into their pet gripes about insufficient and/or inadequate manpower or equipment, or management planning.

6. Opportunity to appraise the "gold in the mine" before embarking on a full-blown program, so that management's emphasis could be directed to the more fruitful areas for improvement.

7. Opportunity to accustom the line supervision and the staff industrial engineers to work together in improvement.

8. Opportunity to appraise the ability and interest of line foremen in growth potential under the two- to five-year program to follow.

9. Finally, the fact that observers other than the foremen

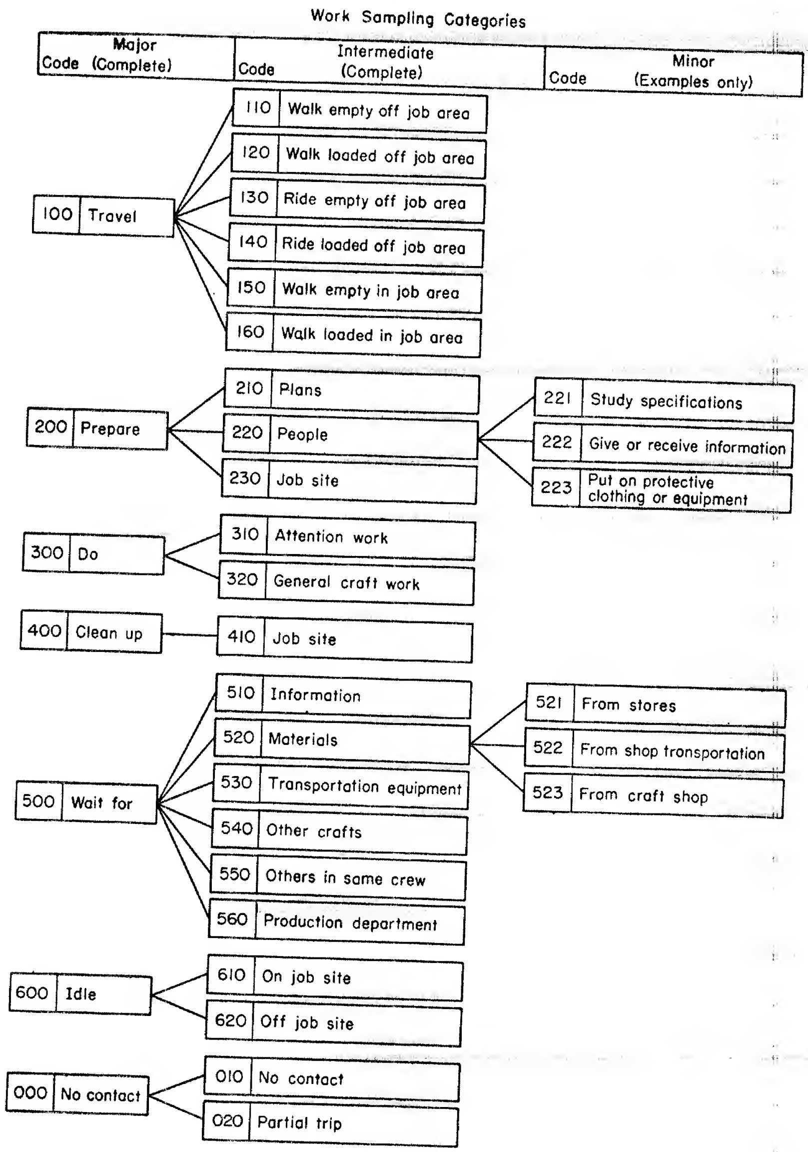

Work Sampling Categories
Major Code (Complete)
Intermediate Code (Complete)
Minor Code (Examples only)
100 Travel
110 Walk empty off job area
120 Walk loaded off job area
130 Ride empty off job area
140 Ride loaded off job area
150 Walk empty in job area
160 Walk loaded in job area
200 Prepare
210 Plans
220 People
230 Job site
221 Study specifications
222 Give or receive information
223 Put on protective clothing or equipment
300 Do
310 Attention work
320 General craft work
400 Clean up
410 Job site
500 Wait for
510 Information
520 Materials
530 Transportation equipment
540 Other crafts
550 Others in same crew
560 Production department
521 From stores
522 From shop transportation
523 From craft shop
600 Idle
610 On job site
620 Off job site
000 No contact
010 No contact
020 Partial trip

Fig. 13-1

would be unable to recognize by sight 600 different men gave the foremen the job of observer almost by default.

Selection of Categories

The Work Sampling program was launched in a meeting of supervisors, industrial engineers, and plant management, where objectives were discussed, a tentative timetable was set up, and general agreement was reached on the desirability of using only line supervisors as observers.

During the course of providing individual and small group instruction in the making of observations, the industrial engineers saw the need for development of a uniform series of category definitions. Since use of tabulating cards for compilation of results was contemplated, the use of standard activity categories was necessary in order to have consistent results, correct interpretation of data, and versatility in presentation of results.

A series of conferences by the staff industrial engineering group produced the category definitions shown in Fig. 13-1. These categories are obviously tailor-made for the use of Work Sampling observers in this particular situation. However, they have been found to fit many maintenance operations in other plants.

It will be noted that code numbers are shown in Fig. 13-1. Major, intermediate, and minor classification codings are for subsidiary activity breakdowns, so that a one-, two-, or three-digit number may be used, depending upon the degree of detail desired and the number of observations contemplated.

WORK SAMPLING CATEGORIES AND DEFINITIONS

Code

110 *Walk Empty—Off Job Area**

A. Walking empty handed.

* Job area is defined as: that area immediately surrounding the actual installation and/or including a temporary work bench.

120 *Walk Loaded—Off Job Area**

A. Walking carrying material, tools, parts, etc., including push hand truck.

i.e. Mechanic going to or from Tool Room carrying tools.

Mechanic going to or from Craft Shop carrying parts or material for installation or revision prior to installation.

Mechanic pushing hand truck with parts, tools, or material to Production Department Area, Craft Shop or Tool Room.

130 *Ride Empty—Off Job Area**

A. Riding on scooter, fork truck, or shop truck.

i.e. Gang leader or preparation man riding scooter.

Equipment operator riding fork truck or tractor.

Shop transfer men riding fork truck or tractor returning to Craft shop or Stores to obtain material or parts.

Riding in shop truck enroute to outside vendor for material or parts, or returning from delivering material to be returned, exchanged, altered or repaired, by an outside vendor.

140 *Ride Loaded—Off Job Area**

A. Riding carrying material, tools or equipment on scooter, fork truck, or shop truck.

i.e. Gang leader or preparation man riding scooter from Prod. Dept. area to Craft Shop with material or parts to be altered, or riding scooter from Craft Shop, Tool Room or Stores with material, or parts, to be used on installation.

Equipment operator riding on lift truck or tractor from Prod. Dept. area carrying material, parts, tools, or scrap, to Craft Shop, Tool Room or Salvage Yard.

Equipment operator and/or shops transfer men traveling from Craft Shop, Tool Room, or Stores carrying material, parts, or tools, to site for installation.

Riding in shops truck to or from outside vendor with

material, parts, or tools to be altered, exchanged, repaired, or returned.

150 *Walk Empty—In Job Area**

A. Walk empty handed.

160 *Walk Loaded—In Job Area**

A. Walking carrying material, tools, etc. in Job Area.

i.e. The Calender Job, where welding table is adjacent to #10 Stove and work area extends to north end of building. However, the area should not extend to more than one building.

Prepare

210 *Plans*

A. Look over, or pre-inspect job site or parts to determine what is needed and/or what is to be done.

i.e. Gang leader, preparation man and/or mechanic checking site of installation, material or parts, with blueprints, sketches or drawings.

Gang leader, preparation man or mechanic making drawing, or sketches for parts to be made or altered in Craft Shop.

Gang leader, preparation man or mechanic making out stores requisition for material to be delivered to job site.

Prepare

220 *People*

A. Study, sketches, prints and specifications, route sheets and procedures.

B. Give or receive job assignments and instructions.

C. Obtain information from other craftsmen, engineers or production personnel.

D. Answer and make phone calls.

E. Put on protective clothing or equipment.

i.e. When gang leader, preparation man or mechanic peruse prints, specifications or sketches, before starting installation.

Normal job assignments.

* Job area is defined as: that area immediately surrounding the actual installation and/or including a temporary work bench.

Gang leaders or mechanics discuss peculiarities of job assignments relative to making correct installations.

Prepare

230 *Site*

A. Obtain and prepare material or equipment.
B. Set up or arrange material, tools or equipment.
C. Set up ladders or assemble scaffolds or platforms.
D. Shut off or lock out any service, water, electric, oil or gas. Hang safety tags on controls.
E. Hang up or lay down equipment or material to protect surrounding areas, equipment or parts.
F. Make room to work.
G. Clean area in which job is to be performed before starting work on job.

i.e. Bring material such as pumps, motors, conveyor, etc., from storage to site of installation.
Hang chain block or install temporary I-Beams for chain blocks, set up scaffolds or ladders.
Hang asbestos curtains for fire protection.
Lay scrap felt on floor, grease and oil drippage.
Move production material from area.
Bring tools from tool box when unable to bring tool box to site.

Do

310 *Attention Work*

A. Stand by for safety protection.
B. Watch while training or being trained.
C. Watch machine tools while operating.
D. Watch machine or equipment to determine trouble or during test run.
E. Stand by while new installations are being tried out.

i.e. Stand by with fire extinguisher while burning or welding is being done.
Stand by while work is being done in sub-station by craftsmen other than electrician.
Stand by while work is being done in gaseous stoves or other hazardous area.
Stand by to hold ladder while man works from ladder.

Stand by at sprinkler valve while work is being done on sprinkler lines.

After machine has been assembled, stand by for run in, to check bearings, belts, etc.

Helper stands by while mechanic does intricate part of work, ready to lend a hand when necessary, such as establishing center lines, bench marks, etc.

Do

320 *Craft Work*

A. Handle material, tools or equipment within job site. Including all walking within site.

B. Gauge, inspect, or otherwise check or test work.

C. Clean parts or equipment.

D. Do craft work.

E. Apply protective coating or covering on parts for storage.

i.e. Arrange material or tools for installation.

Take measurements of roll dia., bearings, etc.

Wash, scrape or otherwise clean parts for reinstallation or storage.

Actual work with hands, such as removing guards, chains, bearings, or parts of equipment.

Paint rolls, bearings, and machined surfacing with protective coating for storage.

Helper sent to tool kit (stored in work area) for tools or equipment essential to installation in progress.

410 *Clean Up*

A. Aside or dispose of material, tools or equipment, including scrap, excluding any traveling.

B. Take down ladders, or disassemble scaffold or platform.

C. Put facilities back in service and remove safety tags from controls.

D. Take down safety barriers or ropes.

E. Take down or pick up equipment or material protecting surrounding areas, equipment or parts.

F. Remove protective equipment or clothing.

G. Sweep up area and replace any items that are out of place.

i.e. Generally police the area after job is completed.

Gather scrap thru-out the Plant.

510 *Waiting for Information*

From Supervisors, Gang Leaders, Engineers

A. Job Assignments—where, what, when.

B. Instructions—How, why.

C. Job Approval—Changes or continuations.

D. Job Specifications—New or revised.

E. Other Information—Job numbers, etc.

i.e. Men working on job run into difficulty—put gang leaders call on, waiting until he arrives.

When men are assigned to job, where verbal instruction will be given by engineer or supervisor.

After job is completed waiting for new assignment.

520 *Waiting for Material*

From stores, shops transportation, Craft Shops.

A. Tools

B. Equipment

C. Supplies

D. Parts

E. Raw Material

i.e. Waiting for preparation men to bring special tools from Tool Room.

Waiting for equipment or parts to be brought from storage for installation.

Waiting for

530 *Transportation Equipment*

A. Elevators, cranes, hoist, fork trucks, etc.

i.e. Waiting for elevator.

Waiting for lift truck.

Waiting for crane, being used by Production or other crafts.

Waiting for Shop or Yard truck.

Waiting for outside vendors truck where something is being shipped out.

Waiting for

540 *Other Crafts*

A. Waiting for other crafts to complete their work.

i.e. Waiting until Sheet Metal men remove guards, hoods, or duct.

Wait until Electrical men disconnect motors.
Wait until Pipe Shop men remove pipe connections.
Wait until Carpenters build skids, scaffolds, etc.

550 *Waiting for Others of Crew*

To arrive at job site, due to unbalanced crew condition.

i.e. When two (2) men are assigned to a job, one man sent to Shop, Tool Room or Stores for parts or supplies, or only one man can work at that particular moment because of nature of task to be performed or of limited space.

560 *Waiting for Production*

A. Release equipment.
B. Provide space to work.
C. Provide information.

i.e. Change rolls, knives, parts, etc., on Calender, German Mixers, Dicers, etc. Must wait until last batch is run out before machine can be shut down.
Move raw material stored in area where new machine is to be installed.

610 *Idle on Job*

While work can be done.

i.e. Mechanic idle in work area or immediate vicinity.
Resting while work can be done.

620 *Idle off Job*

While work can be done.

i.e. Mechanic visiting another department for reasons not connected with his work.
Personal time (lavatory, personal conversations, etc.).

Further explanations of the major categories are shown above. These definitions were circulated to all observer-foremen, and individual practice trips were made by industrial engineers with each foreman on each shift in each craft, to make sure that each activity category was thoroughly understood, before actual recording of observations on a regular basis was begun. Periodic reviews of category definitions were set up with each observer-foreman.

The necessity for randomness was complicated by the fact that foremen who supervised mechanics engaged in roving repair and construction work were unable to complete a trip in less than two to three hours, and in some cases were unable to locate all of their men in a half day. While these extreme cases decreased gradually over several months of sampling, primarily because of better planning and more complete knowledge of the assignments and locations of each employee, the concept of randomness, under these conditions, must be considered in a slightly different light than is usual in Work Sampling.

Randomness in Work Sampling usually is considered as applying to the time interval between cycles, or trips, of observations, and hence a schedule for making cycles or trips can be set up in advance, and held to by the observer. This is particularly true where little or no walking is involved, and the cycle or trip takes not more than five or ten minutes.

While such a scheme was used for those foremen who had all their employees at relatively fixed locations, such as machine shops, sheet-metal shop, electrical shop, weld shop, pipe shop, machine-erection shops, cribs and storerooms, etc., it could not be used for such groups as field welding, electrical maintenance, and building maintenance. In these latter cases, no scheduled times were assigned, and the foreman was instructed to record the time when he observed each man each day, to the nearest quarter hour, with the randomness to be checked at the end of each month by a *c* chart.

Several systematic nonrandom influences developed in these latter cases. First, the tendency of a supervisor to favor certain times during the shift was noted. This was corrected by explanation of the serious effect this had on the reliability of the results. Another error was the failure to complete a trip, that is, failure to observe *all* his men on each trip, thus endan-

WORK SAMPLING—MECHANICAL STORES

Opn. #150

Observer Keller—24

Sheet 1 of 1

Trip		18 06 Leaders		00 Stores Attendant										23 Mtr Pool		00 Salvage Yard					
Date	Time	Flick 1814	Salm 2354	Bowers 4809	Grimm 5914	Graybill 7030	Kachel 8493	Marley 3581	Moser 2696	Schoenberger 10224	Warfel 1146	Worral 11694	Graham 4591	Kaiser 3892		Gehr 2358	Dull 10308	Gilner 3260	Sherman 19773	Stone 16201	

TRAVEL

Walking:	
Empty	110
Loaded	120
Riding Empty:	
Tow Motor	131
Krane Kar	132
Del. Truck	133
Scooter	134
Tractor	135
Scrap Truck	136
Riding Loaded:	
Tow Motor	141
Krane Kar	142
Del. Truck	143
Scooter	144
Tractor	145
Scrap Truck	146

CLEAN UP

Gen. Work	411
Clean Stock Bins	412
Clean & Prepare Parts for Storage & Dispensing	413

PREPARE

Check or Meas. Parts	211
Inv.—Annual	212
Inv.—Motor Pool	213
Inv.—Daily Phys. Check	214
Inv.—Spare Parts	215
Fill Out Shipping Sheets & Move Orders	217
Write-up Personals	218
Other Paper Work	219
Give or Receive Job Assign	221
Telephone Calls	222
Give or Rec. Info-Customers	223

WAIT FOR

Info. from Ldr. or Foreman	511
Info. from Customer	512
Orders to be Typed	513
Mat'ls, Frt, Expr, Mail, etc	521
Tow Motor	531
Krane Kar	532
Other Transp. Equip	533
Customers at Counter	541
Others of Same Crew	550
Prod. Dept. to Provide Space to Work	561

DO

Attend Meetings	311
Unload Trucks—Frt	321
Unload Trucks—Other than Frt	322
Operate Tow Motor	323
Operate Krane Kar	324
Operate Delivery Truck	325
Dispensing Mat'ls & Parts	326
Stocking Bins	327
Sorting Scrap Mat'l	328
Checking in Mat'l	329

IDLE

On the Job	610
Off the Job	620
Rest Period	630
Lunch	640
Personal	650

NO CONTACT

With Worker	000
Assigned Outside Plant	030
On Assigned Trip	040

Fig. 13-2

Observer Rainar—25
Sheet 1 of 1

WORK ACTIVITY SAMPLING—WELD SHOP AND FIELD

Opn. # 114

Trip		01 Ldr.	02 1st Class																03 2nd Class				05 Helpers		
Date	Data	Reno 1753	Castleman 2334	Donnelly 1842	Dorsey 13268	Erb 1816	Floyd 1383	Hagen 1754	Hagelgans 2550	Harris 4515	Kilgore 2315	Mengali 1756	Neuhauser 1758	Pickel 3338	Rainar 194	Sauder 1239	Sheckard 1764	Shenk 7016	Shindle 1760	Bair 3703	Henry 12494	Leisey 2010	Sager 925		Eckenrode 18764	
	Act.																									
	Time																									
	For																									
	Act.																									
	Time																									
	For																									
	Act.																									
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	Act.																									
	Time																									
	For																									
	Act.																									
	Time																									
	For																									

TRAVEL
11 Empty
12 Loaded

PREPARE
21 Plans
22 People
23 Site

CLEAN UP
41 Clean Up Work

DO
31 Attention Work
32 Craft Work

WAIT FOR
51 Information
52 Material
53 Transp. Equip.
54 Other Crafts
55 Others of Crew
56 Prod. Dept.

IDLE
61 On Job
62 Off Job

NO CONTACT
00 With Worker

FIG. 13-3

WORK ACTIVITY SAMPLING—MACHINE SHOP & SAW SHED (2300 to 0730)

Opn. #117 For 11/22–12/20

Observer Kasper—12
Sheet 1 of 1

Trip		21 Machinist Assemblers						02 1st Class Machinists					03 2nd Class				99 App.		10 Janitor							
Date	Time	Denlinger 4583	Geralls 1549	Krantz 1566	Miller 2340	Weaver C. 1583		Giandalia 5155	Krantz 2434	Weaver 14209	White 4704	Yodor 2611	Charles 19306	Ezard A. 19308	Sheckard 19678		Gerz 21317		Smith 1963							

TRAVEL
11 Empty
12 Loaded

PREPARE
21 Plans
22 People
23 Site

CLEAN UP
41 Clean Up Work

DO
31 Attention Work
32 Craft Work

WAIT FOR
51 Information
52 Material
53 Transp. Equip.
54 Other Crafts
55 Others of Crew
56 Prod. Dept.

IDLE
61 On Job
62 Off Job

NO CONTACT
00 With Worker

FIG. 13-4

gering the drawing of inferences, since the contributions of individual employees to the final results were unequal. This, too, was explained, and the cause removed by assisting the foreman to avoid biasing the results.

Taking the Observations

A few of the forms used for collection of data are shown in Figs. 13-2 to 13-4. An example of the punched card used is shown as Fig. 5-3. While in some cases observations were made by foremen directly on mark-sensed punched cards (employees' names and other fixed information already pre-punched and interpreted), many foremen preferred to use observation forms such as those shown. In these cases, transcription to mark-sensed punched cards was made by clerks, at comparatively little expense.

Simple calculation reveals that the number of observations made during a month was enormous. Average number of trips per day steadied down to about 4. Therefore, 4 trips per day, times 600 men, times 20 days per month, yields 48,000 man-observations per month! Obviously, some mass data handling method, such as punched cards, was a vital necessity in order to carry out the program.

Results

The foremen acted as observers continuously for about six months, during which close cooperation among all involved in the program yielded some highly interesting results.

Probably the most immediate benefit was the enforced, periodic look at each employee, by his foreman, several times each day. The foremen were instructed to make whatever method improvements seemed desirable, whenever and wherever they could. Many crew unbalances, unnecessary on-the-job delays, and instances of poorly planned work were cor-

rected. In the long run, this type of on-the-job method improvement by foremen may well be the most significant result of the program.

Summarizations of results were made for each observer, on a weekly basis. Control Charts for each observer were set up and posted weekly, to reflect three phases of the results:

1. Distribution of observations by time interval, in the form of a *c* chart, to note nonrandom sampling influences.

2. For each category, a *p* chart to reflect stability or change as the program progressed.

3. A bar chart showing total observation distribution.

These charts had their primary use as subjects for discussion in weekly conferences held by each general foreman with each foreman under him. However, they enable the engineers to assist in removal of nonrandom sampling influences and to evaluate the improvement potential.

The question of whether foremen will bias results by deliberately miscalling certain categories came up very early in discussions of Work Sampling. There is, of course, a tendency on the part of foremen to protect themselves against unknown uses of the data they collect, prompted by fear of retribution, and deliberate miscalling of observations is the most obvious way to protect themselves. However, this tendency can be dealt with, and was in this case, by use of two convenient devices:

1. When deliberate bias occurs, it will nearly always be revealed in the Control Charts for category proportions by a stratification appearance in the category *not* being recorded sufficiently often, as well as in at least one other category (the one recorded in lieu of the correct one). Hence, since no change is shown on the charts, indeed an unnatural constancy is exhibited, it is a fair conclusion that no *improvement* is taking place!

2. Use of occasional check studies by general foremen on crews of individual foremen, followed by a significance test by use of the Control Charts. This is the more powerful device, but must be used with discretion. When the general foreman finds significantly different results than the foreman finds, the onus is usually on the foreman to prove his proportion is the true one.

Actually, of course, this type of bias occurs almost solely through failure of the foreman to understand that no retribution will follow *correct* recording. In this case, a major contribution to improvement was made by continued demonstrations of good faith by engineers and management generally, so that the fear which prompted early bias in recording gradually lessened, and results became independently repeatable.

As a result of about six months of these studies, along with test applications of devices for measurement of work itself, a major program was instituted in 1955, for achievement of better planning and control of maintenance and construction work. This program hinged about several key steps:

1. Continuation of Work Sampling on a periodic basis, for reliable measurement of improvement. A full-time independent observer was added to the engineering staff, to make spot studies and equipment studies, and to intensify the sampling where it became desirable.

2. Creation of the job of methods planner. This group was charged with preplanning of major maintenance and construction work. The necessary communication and follow-up to make these plans effective were also designed and installed.

3. Provision of accurate and meaningful budgetary cost and man-hour reports, using standards arrived at by successive approximations as knowledge and methods improved.

4. Provision of automatic data feedback for continuing

improvement in planning of work. This phase is well under way, and of course promises greatest long term gain.

Obviously, this entire program required use of a system for handling large masses of information economically. The company's punched-card facilities were used wherever possible, and an IBM Type 650 computer is now being programmed for the major data-handling peak which is fast approaching.

There is no doubt that the great key in all this program has been the *desire* for improvement by all concerned and a highly gratifying willingness to work together. Certainly neither Work Sampling nor any other phase of this program could have succeeded without this human cooperation. But in this situation, the technique of Work Sampling provided the catalyst with which to achieve this trust and faith so vital for improvement.

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Case Study D: Materials Handling

The Problem

In this case, a household appliance factory used Work Sampling to help measure materials-handling costs. The factory, manufacturing hot-water heaters, was engaged in a continuing program of cost reduction. Many of the proposals made under this program involved some change of materials-handling equipment and procedures. Up to the time of the Work Sampling study, many of the costs associated with materials handling had been hard to identify and measure. Work Sampling proved to be an effective means of measurement in this situation.

Briefly, sheet steel was handled by fork truck through receiving, stores, various blanking and forming press operations, and then onto a conveyor system for glass coating, welding, and assembly. Finished, crated heaters also were handled by fork truck. Approximately twelve hundred heaters were manufactured each day. The plant was unionized, and all direct-labor operations were covered by stopwatch time studies. The methods and standards department consisted of a chief industrial engineer and 11 men.

From time to time various proposals had been submitted to extend the conveyor system back to include the initial press

operations. It seemed that these proposals had never been fully supported by facts, however, because information was lacking concerning the following:

1. The amount of in-process handling required by the present system of fork truck moves through press operations
2. The operating effectiveness of the fork trucks themselves

"In-process" handling refers to the handling of materials within a workplace, as distinct from the actual performance of work on the product. Most production operations require a certain amount of this, as the work is transferred from temporary storage to the machine, and again as the work is placed in temporary storage after the operation. Sometimes these considerable amounts of time are overlooked as costs of a materials-handling system. One of the advantages of conveyor systems is that if properly installed, some of this in-process handling may be reduced.

Why Work Sampling Was Used

It is possible to extract in-process handling time from the time standards which exist on the job. Even so, there are other handling times which take the form of percentage allowances which should be determined objectively. Finally, not all the indirect labor was covered by standards, and some of this activity was materials handling. It was thought that Work Sampling would give a *direct* measure of the time spent in in-process handling, and in addition would help in the determination of certain time-study allowances.

In addition to the in-process handling done by operators, a study was made of the activity of the six fork trucks assigned to the area in which the initial press operations were performed. The objective here was not only to provide estimates of possible savings in the event of changes reducing

demands for fork-truck moving but also to appraise the effectiveness of fork-truck operation as it then existed.

Organization for Work Sampling

Time-study engineers regularly assigned to the area conducted the study. In addition, the union shop steward and the foreman were trained in the technique of Work Sampling, so that they would be able to make their own check studies. Training was done by a college professor, through an extension center arrangement. Five two-hour sessions were held, plus another two-hour session for a group of supervisors and union officers. In addition, one morning was spent in making trial rounds of observations in the shop.

Twelve rounds of observations were made per nine and one-half working hour shift. Times of observation were selected from a table of random numbers. Numbers from 000 to 569 were taken as they occurred in the table. The study extended over 4 weeks; 6 fork trucks and from 23 to 28 men were studied. Total number of observations for the trucks was 1,427, and for the operators, 6,173. The truck study will be discussed first.

Selection of Categories and Results

Categories of activity, with percentages of observations in each category, were as follows:

Category	%
1. Move with load	13.4
2. Move, no load	15.7
3. Adjust stacked material	3.1
4. Move with die (a die is a large, heavy steel press tool)	0.4
5. Assist in install or remove die	0.9
6. Not in use, no work available	46.1
7. Not in use, operator absent	9.4
8. Not in use, maintenance, adjustment, or inspection	6.3
9. Truck not in area being studied	4.7
	100.0

These percentages did not tell the entire story. Further

study of results showed that while a minor time cycle existed, in only 0.2 per cent of the rounds of observation were all trucks in use. In only 1.3 per cent of the rounds were as many as four trucks in use at the same time. It seemed obvious that there was not enough work to keep six trucks busy.

The category Operator Absent was recorded 9.4 per cent of the time. This amounted to an average of 53 minutes a day. Personal time allowed operators was 5 per cent, or less than 30 minutes a day. Actually, the operators realized what management did not, namely, that too many trucks were assigned to the job. Also, maintenance, inspection, and recharging were supposed to be done at night. Only emergency repairs and adjustments should have been made during the periods studied. Yet the trucks were idled for maintenance 6.3 per cent of the time. This was considered to be an unsatisfactory condition.

Finally, the study showed that die moving (0.4 per cent) and die handling (0.9 per cent) required a total of only 1.3 per cent of the time. The significance of this was that die handling as such was classified in the job evaluation plan as requiring "exceptional" skill. This led to the payment of premium to all drivers who handled dies. The study showed that all this work could easily be handled by one truck. Assignment was made accordingly; in addition, crew assignments were specified more closely among the machinists who installed the dies.

Specific actions taken as a result of the truck study were:

1. The number of trucks in use in this area was reduced from six to four.

2. A new system of truck scheduling was instituted, to reduce travel and waiting time.

3. An investigation was made of maintenance practices. This resulted in action which reduced maintenance time during the shift almost to zero.

4. Since management felt that the unsatisfactory conditions were primarily their own fault, no attempt was made to "crack down" on drivers. However, it was pointed out that no driver would be overworked as a result of the changes.

5. As a result of the study, motion-picture techniques were used to develop standard times for planning moves. The Work Sampling was not used in this, but the conditions Work Sampling revealed were felt to warrant the further study.

The Work Sampling study made of the operators in the area was quite similar to any other study of production workers in a standardized job situation. The only differences lay in the selection of categories in such a manner as to separate out the in-process materials handling. Although careful breakdown of existing methods descriptions should enable us to get this information, Work Sampling seemed a more positive approach. Also, management was in the process of attempting to build up basic measuring techniques for materials handling, and had decided to use Work Sampling as part of this program.

Results of the Work Sampling study of direct-labor operators in the area serviced by the trucks were as follows:

Category	%
1. Operating press, all elements	27.1
2. Press and tool adjustment	6.7
3. Materials handling, into press	20.6
4. Materials handling, out of press	27.3
5. Operator absent	5.8
6. Delay for material supply	3.3
7. Delay for material removal	5.2
8. Delay, other	4.0
	100.0

A few general remarks are in order concerning these results. First, press work involves a very rapid work cycle on the part of the machine, and thus the "work" part of the operators' activity is bound to be low. Next, the operators had to stack finished work parts quite carefully. Not only were the parts

rounded and slippery, but also they were being stacked on pallets which then were moved by fork truck. Finally, all these jobs were being performed at a work pace averaging 27 per cent above the time-study men's concept of "normal," as reflected in the standards covering these jobs. Thus the results were by no means indicative of an unsatisfactory performance under the presently specified method.

A comparison was made between the actual Work Sampling results as they pertained to materials handling and the time allowed for materials handling in the various time standards covering these jobs. It was discovered that observed materials-handling activity exceeded that "built in" to the standard by about 15 per cent. Obviously, this extra time must have come at the expense of some other element. In this case it was found that "operating press" and "tool and press" adjustment were less than expected. What had been occurring was that the operators had become a little sloppy in these elements because insufficient time had been allowed for the materials-handling elements. When the situation was corrected, incidentally, quality of product improved significantly.

To pursue the materials-handling aspect, the press operations were synthesized (using elemental human work times) for a method which would have conveyorized the operations. It is important to note that the Work Sampling showed how much time was now spent in materials handling. This proportion of time is the *maximum* which can be saved—and to save it, materials handling must be reduced to zero. Thus, by using conveyors, *some* of category 4 (Materials Handling, Out of Press) time could be saved, perhaps, but the 27.3 per cent observed in this category represents the absolute maximum available for cost reduction purposes. From this must be subtracted the time to handle work out of the press in a new method.

To generalize for a moment, it has been the sad experience of some managements to have been put in the position of having installed materials-handling "systems" on the basis of glowing claims, only to find that expected savings did not materialize because the potential for large savings *never* existed. In other words, a good cost analysis could not be made without the sort of over-all measure which Work Sampling can provide. This is not to deprecate the importance of materials handling. Rather it is to say that management realizes that it is costly to move and store material. The authors suggest that if factual information is available, this cost may be determined, and serve as the basis for better economic evaluation of proposed change.

In this particular case, it was decided to handle material by fork truck to the first operation, and to handle by conveyors from that point on. Also, operating instructions were clarified to ensure more attention to oiling dies and to inspection procedures. The combination of Work Sampling and synthesized work times enabled management to justify the expense of the change. A Work Sampling study was made after two months' operation. This study showed that the change was for the better, since all materials-handling expense was less than previous cost by an amount sufficient to more than pay for the change.

To summarize, some costs of materials handling can be determined quite easily. Among these are fork-truck costs, costs for conveyor installations, space costs in warehouses, and so forth. Primarily, *all* such expense is due to handling and storage. It is more difficult to measure materials-handling expense when those handling the product also perform direct-labor operations on it. For this situation, Work Sampling has proved to be an effective tool of analysis.

15

Case Study E: Loom Utilization

The Problem

A carpet manufacturer was engaged in a program to improve the plant's production control. Several objectives of this program could be met by improving office and planning procedures. The ultimate improvements, however, in addition to resulting in a better inventory situation, should also benefit shop operations. In order to have a complete appraisal of the progress of the entire program, some analysis of shop activity was necessary. It was decided to take a Work Sampling study, aimed particularly at measuring the time which could be saved by better production control.

Since capital investment in looms was quite considerable, any down time resulting from lack of yarn was expensive. The replacement cycle for the yarn was from six to eight weeks. Furthermore, good production control was necessary in order to keep inventory low, and service at the level demanded by the trade. Therefore a loom standing idle for lack of yarn represented a matter of some concern to management. Over the year preceding the study, production control performance had been steadily worsening. This was not the fault of the mill, but the mill was being penalized through short runs, waits for yarn, and irregular weave schedules. Also

every time a beam or creel (these are devices for storing yarn at the loom—the yarn goes from these directly to the loom) had to be cut or changed, production was lost and the cost of direct labor was increased. Therefore, as the program of improvement proceeded in the office, the effectiveness of operation of the mill should also improve. The Work Sampling study was undertaken to provide measurement of this improvement, and also to find how much improvement could be expected.

In addition to measuring the effects of production control on the shop, management wanted to check certain allowances given, and to establish a bench mark for the particular level of operation. The line supervisors were told to keep a careful record of unusual occurrences, to help establish this level.

The mill was not unionized. One of the reasons for production control improvement was to permit better scheduling of personnel. Also, since the market was seasonal, it was possible that a different policy might be necessary at different times of the year, that is, that shorter runs of different types of carpet would be made at slack times. It was hoped that the study would give information which would aid management in formulating this policy.

Why Work Sampling Was Used

Work Sampling seemed an obvious tool to obtain the type of information desired. As a matter of fact, Tippett's first work was done in a similar situation. Basically, information was desired concerning a condition which definitely was not scheduled, namely, running out of raw material. Furthermore, it was desired to observe the looms, and not the personnel. While some data on the personnel would of course be collected—since people run looms—loom utilization was what management was after. The system of timekeeping in

effect made it quite difficult to obtain the needed information simply by examining time cards of the weavers.

To generalize, what was wanted was an over-all measurement of what was very definitely an undesirable nonstandard shop condition. To look ahead, management planned a program which it was hoped would result in change for the better. Therefore whatever measurement technique was chosen should also have the characteristic that future comparisons could be made easily and consistently. In such situations, Work Sampling has proved to be quite effective.

Organization for Work Sampling

The industrial engineering department of the plant conducted the study. The chief industrial engineer served as director. The consultants who were working with production control supplied a small amount of training, but not much was necessary. A time-study man was assigned to take the observations. The industrial engineering department was staffed by six methods and time-study men, who were experienced in the shop and were very capable. Two of these men had had previous experience in Work Sampling, as had the chief industrial engineer.

No other special comment is needed concerning the organization. The Work Sampling study was simply another assignment for the industrial engineering department. It was within the scope of their ordinary duties, and the results were sent to management in the same manner as other performance reports issued by the department.

Selection of Categories

In selecting the categories, the main objective was to separate out those delays which could be inferred to be a result of production control performance. In addition, the working

categories were selected in such a manner that they could be checked against existing incentive rates. The categories use terminology of the weave shed, but require little further explanation. A "runout" means that the creel or beam is empty and that a new one must be tied in to the loom. A "cut-out" means that there is still yarn on the beam or creel, but that a change of color is wanted badly enough to warrant the expense of tying a new beam or creel in to the loom. Runouts occur normally; cutouts reflect poor production control and are extremely expensive. The categories selected were as follows:

1. Running time
2. Hand time in weave rate
3. Beam change—runout
4. Beam change—cutout
5. Weaver absent
6. Change creel—runout
7. Change creel—cutout
8. No pile yarn or pile beam
9. No binder or stuffer beam
10. No orders or not scheduled (loom idle)
11. No manpower
12. Machine repair—major
13. Wait for decision (production control)
14. Samples—production looms only
15. Loom repair—done by fixer (mechanic)
16. All others
17. Change over loom (to different pattern)

Collection of Observations

An observation sheet of a very simple design was used (Fig. 15-1). From the observations made on this sheet, a series of tabulating cards were punched. This punching was quite

simple, and made statistical analysis of the results a much more rapid procedure. Five rounds of observations were made each day, on the day shift only. It was decided that two weeks' observation would be sufficient. By that time almost seven thousand observations would have been obtained, which would give a level of reliability sufficient for the study's objective. The plant was working five and a half days per week.

Date 4-21-55
Time 1048

Loom	Element	Loom	Element	Loom	Element	Loom	Element
333-1	1	310-1	1				
332-1	2	303-1	2	402-9	1	375-3	12
331-1	13	309-1	1	450-9	1	376-3	11
330-1	10	304-1	2	417-8	10		
329-1	1	308-1	11	403-9	16	424-8	1
328-1	1	305-1	1	416-8	1	423-8	15
327-1	1	307-1	2	419.8	6		
326-1	16	306-1	1	415-8	1	601-6	10
325-1	10			418-8	1	600-6	10
324-1	1	279-1	16				
323-1	3	280-1	1	500-4	8	628-7	7
322-1	15	281-1	16	550-5	10		1

Fig. 15-1. Loom-utilization-study observation sheet.

There were no special precautions necessary in collecting the data. The observers were experienced men, who had done Work Sampling before. The employees were informed of the study's objectives, and of the fact that it would be taken.

Results

The results of the study are shown in Table 15-1. Category 10, No Orders or Not Scheduled (Loom Idle), was designated category B, and carried separately in the summation of results. This was done in order to verify certain allowances which were

given as a percentage of scheduled loom operation. Also, by presenting results in this fashion, it was felt that available loom time could be obtained directly.

The results were broken down by loom width, which was the scheduling breakdown most convenient in interpreting performance. Also, type of loom was considered. The significant values were as follows:

1. Category 8, No Pile Yarn or Pile Beam, represented a failure of production control to have the proper raw material on hand. This category represented the possible area for direct improvement through better production control. It should have been almost zero.

2. Creel Cutout, category 7, is very undesirable. Supplementary records kept during the study showed that this too was caused by poor scheduling.

3. The 12/4 Velvet looms were working three shifts, and still could not meet customer demand. At the same time, category B (category 10 in original list), No Orders or Not Scheduled, was 13.9 per cent of the total. Since orders were available, it was obvious that scheduling was at fault.

4. Change Over Loom (category 17) was quite satisfactory. This is worthy of note, since the foremen had estimated that this activity took as much as 10 per cent of the loom time. This reflected favorably on production control. The inference was that yarn control was inadequate, but parts of loom scheduling of pattern change were satisfactory.

5. To take the 12/4 Velvet looms as an example, category 11 (No Manpower) represented a significant loss. What had happened was that the foreman hesitated to call in weavers because there might not be yarn for the loom, and thus wages would be lost.

6. For the most critical looms, possible areas for savings through better production control were considerable. Lump-

TABLE 15-1. SUMMARY OF RESULTS OF WORK SAMPLING STUDY OF LOOM ACTIVITY CONDUCTED BY INDUSTRIAL ENGINEERING DEPARTMENT

Element	% Occurrence				
	12/4 Velvet	16/4–20/4 Velvet	3/4, 4/4, 8/4 Wilton	12/4 Wilton	16/4, 20/4 Wilton
1. Running time	61.3	52.2	32.3	54.1	52.3
2. Hand time in weave rate	10.6	15.0	8.9	11.1	14.3
3. Beam change—runout	7.6	9.6	2.3	2.2	4.5
4. Beam change—cutout	0.2	.....	0.1	.....	0.2
5. Weaver absent	3.9	4.9	6.9	4.8	2.1
6. Change creel—runout	.....	.....	0.7	2.6	2.8
7. Change creel—cutout	.....	.....	2.0	6.6	2.9
8. No pile yarn or pile beam	4.8	6.1	15.3	6.8	10.0
9. No binder or stuffer beam	0.3	0.7	0.4		
11. No manpower	5.7	2.2	0.5	.....	0.2
12. Machine repair—major	0.9	1.9	1.8	2.2	1.0
13. Wait for decision	0.4	.....	5.0		
14. Samples—production looms only	0.2	.....	12.6		
15. Loom repair—fixer	0.8	2.6	3.2	3.5	3.5
16. All others	3.3	3.5	4.9	5.5	4.9
17. Change over loom	.....	1.3	3.1	0.6	1.3
	100.0	100.0	100.0	100.0	100.0
A. No observations—orders available	2,458	974	812	316	1,217
B. No observations—no orders or not scheduled	342	1	488	184	58
C. No orders or not scheduled, % of *A*	13.9	.....	60.1	58.2	4.8
Total number of observations	2,800	975	1,300	500	1,275

ing together categories 4, 8, 9, 11, and 13, for the 12/4 looms, a total of 11.4 per cent is reached. This represents the worst situation, but of course this total is significant for all looms. In fairness, it must be added that only the velvet looms were really critically overloaded with customer orders.

7. In general, the time standards proved out. Results of the study agreed closely with most of the running time and service categories in the study.

The real worth of this study was not only that it measured the current operation, but also that as changes in procedure were instituted in the production control office, the effect of these changes on shop operation could be measured. It was planned to take check studies at intervals of every three months. In general, management could then use the Control Chart principles to measure change. Too often only subjective evaluation of over-all activity is available.

16

Case Study F: Punched-card Accounting Department

The Problem

A punched-card accounting department used 18 machines of various types. The machines had been in use for 20 years. Present performance was not entirely satisfactory, but was adequate. A program was being instituted leading to the installation of an electronic computer. As part of this, a Work Sampling study was planned for the punched-card accounting (tabulating) department. This program had two objectives:

1. To determine the utilization of the various machines
2. To determine the nature and extent of work-load cycles

It should be added that past experience in the installation of high-speed computers has indicated the following:

1. That in most cases present tabulating accuracy must be improved
2. That the total work load may be increased because of new demands for information
3. That the work load probably will be distributed differently among the present machines

Fortunately, many of the changes mentioned above may be anticipated. Planning for the new computer installation is bound to be improved if present work loads are known. It

was for this purpose that the Work Sampling study was made. Only the equipment was studied at the outset. It was felt that this would meet the immediate need, and that a study of personnel might be made later, if necessary.

The director of the study was the assistant office manager. He was a very capable man who had been trained in Work Sampling by a consultant. He had attended a business college, and had little previous experience in statistics. The supervisor and his assistant acted as observers. The consultant assisted in training the observers. This training consisted of a day spent in discussion and development of categories of activity. In addition, the first two days' sampling was used as a basis for further training, and the results were not included in the study.

Eight observations per machine per day were made. It required about a minute for each round of observations. The observation sheet is shown in Fig. 16-1. The study extended over a five-week period in order to include monthly cyclic activity. In this study, the objective was to obtain an over-all picture. It should be realized that in other situations, much more information might be gathered in a similar study.

Results of the study may best be expressed by including the report which was prepared for the committee responsible for installation of the computer. While at first glance it might appear that much detail has been omitted from this report, it should be remembered that the essential objectives were met. An advantage of Work Sampling is that it can be tailor-made to fit a given situation. There is no rigid pattern which must be followed in all studies, regardless of the real requirements. In this particular case, no immediate need could have been met by a much more detailed study, and the additional expense could not be justified. Also, the personnel involved were not experienced, and it was felt that success on a limited

Activity Key

1. Operating and running
2. Operating – not running
3. Summarizing
4. Not running-set up
5. Available
6. Not available (maintenance)
7. Trainee

Date ____________________

Observer ________________

Machine Observed	Time Observations Began							
	8:45	9:52	10:49	11:06	1:09	2:40	3:08	4:30
Key Punch No. 1	1	2	2	2	1	1	2	1
Key punch No. 2	1	1	1	2	1	1	2	1
Key punch No. 3	1	2	1	2	2	1	1	1
Key punch No. 4	5	5	5	5	5	5	5	5
Key punch No. 5	5	5	5	5	5	5	5	5
Key punch No. 6	5	5	1	1	1	1	1	1
Payroll tabulator	3	3	5	5	5	5	5	2
Payroll sorter	1	1	1	2	1	5	5	1
Printing multiplier	5	5	5	5	5	5	5	2
Mechanical sorter	6	6	6	6	6	1	1	5
Ele			1	1	1	5	1	5

FIG. 16-1. Machine-time sampling sheet—tabulating department.

scale was of more value than an exhaustive study which would have involved more training and greater demands upon the time of busy people.

REPORT OF WORK SAMPLING STUDY IN THE TABULATING DEPARTMENT

I. Objectives: Overall—

To determine the machine utilization pattern in the Tab Department. The study will *not* be concerned with the activity of personnel, but rather with the activity of machines.

Objectives: Detailed—

(1) To obtain overall utilization, by machines and groups of machines.

(2) To establish in quantitative terms the nature of whatever cyclic trends exist in the Tab. Dept.

(3) To enable planning to be done to schedule the work required in complete programming of payroll, cost, etc. to the Univac.

Procedure:

The supervisor and his assistant took the observations. Eight observations were made each day. All equipment was covered, including the bookkeeping machines. Randomization of times of observation was done within the hour. Categories were:

1. Operating & Running
2. Operating—Not Running
3. Summarizing
4. Not running, but set up to run
5. Available (no job to put on machine)
6. Maintenance (not available)
7. Trainee

No attempt was made to identify activity with any particular task (such as "running sales report").

Results:

(1) The large chart labeled "Work Sampling Time Distribution in Tabulating Department" gives overall proportion of each activity, as a total and by machine groups. [This is Fig. 9-1 in this book.]

The overall proportions of time spent in the individual categories are not as meaningful in this study as in some others, because "available" time, for example, may be high overall, and yet some machines may have an overload. Therefore, the results are best presented in tabular form, as follows:

	Category (as given previously)						
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
Total, all machines	33.5	14.3	1.8	1.5	45.0	2.1	1.8
Key punch (6 machines)	47.7	19.5	0	1.5	25.4	.5	5.4
Tabulators (3 machines)	23.9	13.2	11.0	4.4	46.0	1.5	0
Sorters (3 machines)	37.8	20.8	0	1.0	30.9	9.5	0
Multiplier, interpreter, verifier, interfiler (1 each)	20.5	3.9	0	.1	75.2	.3	0
Bookkeeping machines (3)	24.4	11.8	0	.9	62.6	.3	0

The cyclic effect of workload was shown by plotting categories by machine groups along a time axis. The supervisors expressed the opinion that these graphs agreed with their own impressions, and in addition gave a numerical value to the fluctuations.

In general, although certain cycles exist, there was no case in which a group of machines were operating at capacity. This is not necessarily an undesirable condition, since most jobs require the use of more than one type of machine, and flexibility is important. But it does indicate that the present equipment can do additional jobs, if the jobs are scheduled to fit the now recognized cycles.

Specifically, now that machine utilization is known, it will be possible to plan and schedule new procedures involving the computer in the light of present "available" time. Not until the present equipment is much more fully utilized should it be necessary to consider new equipment.

The supervisors are to be congratulated for their attention to the details of the work sampling. After the first two or three jobs have been put on the computer, they plan to take another work sampling study to determine the effect of the new procedures on the utilization of machines.

17

Case Study G: Joint Union-Management Study to Determine Machine-shop Allowances

The Problem

A 350-man plant manufactured bearings for the automotive industry. Production workers were on incentive pay. Standards had been set by stop-watch time study. Certain allowances which were "built in" to the standards had been questioned by the union. These allowances had been set while the studies were being taken. Also, several eight-hour production studies had been made to check allowances. At the time of contract renewal, the union held that the allowances were inadequate. Union representatives stated that the allowances for tool attention, materials handling, and inspection had been set under substantially different conditions than now existed. This question of allowances was the only remaining hindrance to the renewal of the existing contract.

Background of the Problem

Union-management relations in this plant were on the whole good. The basic reason for the dispute was that the allowances had become almost traditional. However, requirements of quality of product had been tightened, and

batches of work had to be more carefully segregated. Tool and die attention had become of greater importance. Finally, because of an increasing number of new products, the time-study men had been unable to give enough attention to some of the allowances. Both sides agreed that repetitive and machine-controlled elements of the standards were satisfactory. Rather than submit the problem to arbitration, the union and management decided to conduct a joint Work Sampling study. If the results of the study were acceptable, they would be used as a basis for settling allowances in the standards.

The company was organized in a conventional line and staff type organization. The methods and time-study department reported to the production manager. This group consisted of nine time-study men who set rates, two college-trained industrial engineers who worked on methods, and a head of department, who had little formal education. The head of department was an excellent "shop man," who was widely respected in the plant.

The union was a local of a large international union. The union was organized traditionally, with union officers and shop stewards. In addition, there were four time-study stewards, who had been trained in summer schools conducted by the union and a state university.

The staff of the international union had been participating in the renewal negotiations. It was suggested that a college professor be employed as technical advisor. This was agreed to by both sides. It was further decided that each side would take its own study, and that conditions of observation would be standardized so that the two studies should agree. Neither side would be bound in advance by the study in the event of significant differences in results. A 2σ limit was agreed upon as constituting significance.

Why Work Sampling Was Used

Work Sampling was used in this case for the following reasons:

1. There would be no use of a stop watch or of rating or leveling techniques requiring exercise of judgment.
2. The results could be objectively tested for reliability.
3. The study would be relatively inexpensive.
4. The allowances in question could be measured directly.

Basically, the union was not committing itself to the present method of setting rates. Nor was management submitting as an issue the machine-paced and repetitive parts of the existing standards. The use of Work Sampling avoided many of the "matters of principle" over which rate disputes arise.

Organization for Work Sampling

Two plant time-study men and two union time-study stewards were designated to make the observations. They all were familiar with Work Sampling, although none had had experience in it. The college instructor trained all observers in sessions at which a union staff man and the head of the methods and time-study department were present. Several rounds of practice observations were made, and four three-hour sessions comprised the formal training. It was agreed that all matters of procedure would be handled in similar sessions as the study was made.

Selection of Categories

Because of the nature of the study, categories were selected in such a way that all irregularly occurring work for which allowances were given would be classified into separate categories. This led to quite a large number of categories. These were:

01 Operating machine (hand paced)

10 Operating machine, machine paced, operator idle
11 Operating machine, machine paced, operator gaging
12 Operating machine, machine paced, operator cleaning parts
13 Operating machine, machine paced, operator getting stock
14 Operating machine, machine paced, other than above
20 Gaging parts
30 Handling stock
40 Delay, talk with supervisor
41 Delay, set up machine
42 Delay, cleanup
43 Delay, talk with inspector
50 Tool attention, at grinders
51 Tool attention, at tool crib
52 Tool attention, resetting tool at machine
60 Personal
70 Absent from floor (assumed personal)
80 Idle, wait for material
81 Idle, wait for instructions
82 Idle, wait for maintenance
83 Idle, wait for inspection
84 Idle, no work available
90 Other activity

Collection of Observations

It was decided to collect a total of six thousand observations in each study. Time-study men and union stewards collected data independently of each other. A table of random numbers was used, different times being drawn for each group. Eight rounds of observations per day were made. Observers were excused from other duties. A group of operators was observed which was felt to be typical. From 75 to 80 men

comprised the group. The study extended over two weeks' time.

The collection of data proceeded without incident. All employees had been informed of the study. A careful record was kept of production and other information necessary to establish whether or not the two-week period was indeed typical of plant operations. No specific cost data were made available. It had been calculated that six thousand readings would be sufficient to give proper reliability to the study. Such calculations, incidentally, are discussed in this book. As a simple example, however, the case problem concerning air-line reservation activity may be referred to. Very simply, all that is done is to substitute expected $\bar{p}$ in the formula $\sigma_{\bar{p}} = \sqrt{\bar{p}(1 - \bar{p})/N}$, and to use required confidence limits for $\bar{p} \pm 2\sigma_{\bar{p}}$. Then solve for N.

Results

The results of the study follow. The categories are listed, followed by the per cent observations in each recorded by the union stewards, and by the time-study men.

The first test which was applied to the result was to see if the differences between the two sets of values could have occurred by chance alone. In other words, were there any systematic errors of observation which would have resulted in two different "populations" of data? The largest difference occurred in category 10, Operating Machine, Machine Paced, Operator Idle. This category might be held suspect in any event, because it involved one union member's evaluation of another as being idle. In any event, it was assumed that the true $\bar{p}$ was 0.145, or midway between the two values obtained. Solving the equation

$$2\sigma_{\bar{p}} = 2\sqrt{\frac{\bar{p}(1 - \bar{p})}{N}} = 2\sqrt{\frac{0.145(0.855)}{6{,}000}} = 0.009$$

	Category	% Stewards	% Time-study Men
01	Operating machine, hand paced	39.1	38.8
10	Operating machine, machine paced, operator idle	14.2	14.7
11	Operating machine, machine paced, operator gaging	1.3	1.1
12	Operating machine, machine paced, operator cleaning parts	2.1	2.5
13	Operating machine, machine paced, operator getting stock	1.1	0.9
14	Operating machine, machine paced, other than 10–13	3.5	3.4
20	Gaging parts	2.0	2.3
30	Handling stock	4.2	4.2
40	Delay, talk with supervisor	0.6	0.8
41	Delay, set up machine	4.0	3.8
42	Delay, cleanup	0.9	1.1
43	Delay, talk with inspector	0.2	0.2
50	Tool attention, at grinders	2.5	2.3
51	Tool attention, at tool crib	2.7	3.1
52	Tool attention, resetting tool at machine	2.5	2.7
60	Personal	1.9	1.6
70	Absent from floor (assumed personal)	2.9	3.1
80	Idle, wait for material	1.0	0.8
81	Idle, wait for instructions	0.8	0.7
82	Idle, wait for maintenance	0.7	0.9
83	Idle, wait for inspection	0.2	0.2
84	Idle, no work available	8.8	9.2
90	Other activity	1.9	1.6
		100.0	100.0

It can be seen that using the average of the two proportions observed, or *either* one as "correct," the difference between the two proportions could have occurred by chance. Actually, by any accepted test, the results were not significantly different from one another.

The greatest difference, as a per cent of the observed proportion, came in category 40, Delay, Talk with Supervisor. The difference, 0.2 per cent of the observed 0.6 per cent (or 0.8 per cent) was large, percentagewise. However, common sense tells us that the total time involved is quite small. This is a

happy characteristic of Work Sampling, that reliability of very small proportions of activity requires more observations, but the over-all value of these categories also is put in proper perspective. Why worry about a difference of 0.2 per cent of the whole? Rather let us worry about the larger proportions, where real gains can be made through improved management practice.

Production records were checked, and the two weeks which had been studied seemed to be typical of over-all operation. No particularly unusual shop conditions had existed, and there seemed to be no reason to believe that the Work Sampling could not be used as the basis for discussion. Both the union and management agreed that the objective of the study had been met.

As might be expected, management was shocked by the amount of nonproductive time. However, no one denied that the conditions existed. Further, the results were checked with the totals of the "actual hours" charged to the various time cards, and found to be in agreement. In doing this, incidentally, the value of the large number of categories was demonstrated, because it was possible to include all operating time categories, as well as the specific categories then charged to "actual hours," and to compare these with the time cards in detail. That this was possible reassured management that their timekeeping system was satisfactory.

The union felt that the results of the study supported their claim that present allowances were inadequate. For example, Tool Attention, which was observed about 8 per cent of the time, presently was given an allowance of 3 per cent. Also, no allowance at all was given for the various Idle categories; the operators were supposed to punch out when no work was available, however.

Further discussion of detailed results is not in order here. Perhaps the most pertinent comment of all, however, was that of one member of the union bargaining committee, who sug-

gested that management should (1) thank the union for making such a study necessary and (2) hang their collective heads in shame for not doing Work Sampling themselves at an earlier time. As the union man said, management learned about their own operations "the hard way."

When bargaining was resumed, the question of allowances was disposed of very quickly. The allowance for tool attention was increased from 3 to 8 per cent. Other allowances were allowed to remain the same. These were a 5 per cent personal allowance and a 2 per cent "miscellaneous" allowance. In the give-and-take of bargaining, the union agreed to hold off demands for the payment of average earnings when no work was available. Both sides went on record as recommending similar Work Sampling studies in the event of similar disputes in the future.

Management instituted a thorough study of scheduling practice and of dispatching procedures. On the whole, they felt that there had been too little attention given to these areas. One very satisfactory aspect of the study made itself felt in the weeks following the study. Production increased more than enough to pay for the increased labor cost of the new contract. Management felt that this was due to the union's better understanding of management's problems and also to the betterment in morale resulting from joint effort in getting facts from which to make decisions affecting the entire plant. This in itself was very profitable.

In summary, neither side gave up any special "prerogative." No one was committed in advance. And an objective measure of agreement was used. In collective bargaining, as in plant management, operating on the basis of fact seemed to pay off. Particularly in wage-incentive problems, however, the "facts" are sometimes hard to come by. This was one case where Work Sampling provided them.

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Case Study H: Work Sampling of Indirect-labor Work Situations

Work Sampling offers much promise as a measurement technique in the study of indirect-labor cost. In many cases, it is the only technique which will enable management to determine such cost in other than the grossest terms. This chapter will describe the use of Work Sampling in several work situations involving indirect-type jobs.

There are two general factors which have led to the placing of more importance on service or indirect-labor costs. These are:

1. The trend toward automation in office and factory has led to a reduction in machine operators and an increase in such jobs as maintenance work and inspection activity.

2. A desire on the part of management to obtain some sort of control over clerical and service costs per se. Traditionally, much of this work has not been measured because of its irregular nature.

The following examples have several common characteristics, namely:

The work had not previously been measured.

No detailed methods descriptions were available.

The work involved dealing with customers or patients.

There was no intent to set time standards for incentive pay.

The work situations to be discussed are typical of those where a general appraisal is desired, but where professional or customer-oriented personnel are being measured. This class of person usually has a lively interest in his job, and because of the irregular nature of the work, probably never has been exposed to measurement. Also, the objective of the study usually is to find means to allow such persons to spend their time most profitably in dealing with others, and to analyze all nonprofessional or clerical work so that more of this activity can be done by less skilled employees.

Hospital Nursing and Patient Care

A large-sized hospital (500 beds) was faced with a severe shortage of nurses, and with a rising cost of patient care. As a community service, a management society offered the services of its members to help solve these problems. The hospital management felt that a thorough study of nursing activity should be the first objective. The assistant director of nurses acted as the director of this study.

A Work Sampling study was suggested as a means of analyzing the activity of nurses and other personnel engaged in patient care. It was felt that such a study would "put a number" on the various activities of patient care. Also, such a study would serve as a means of publicizing the fact that the hospital management was in the process of working toward a solution of some of the nurses' problems. This aspect of the study was emphasized by asking the nurses to participate as observers for the Work Sampling.

Specifically, the objective of the study was to analyze the activity of all nursing personnel. From this analysis, programs of corrective action were to be planned and executed. While this may seem like a limited objective, really it was quite

sound. Management simply wanted some factual information on which to act. Both the nurses and administrators recognized that a hit-or-miss study might do more harm than good. So an over-all appraisal was set as the objective.

Each floor of the hospital was staffed by a floor nurse, who was in general charge, an assistant floor nurse, from one to three registered nurses, special-duty nurses, who were serving individual patients, from one to three student nurses, and one or two each of nurses' aides and cleaning women.

The floor nurses and their assistants acted as observers. Eight observations per eight-hour shift were taken. Two different floors were studied, and both the 7 A.M. to 3 P.M. and 3 P.M. to 11 P.M. shifts were covered. Times of observation were taken from a table of random numbers. The floors selected were felt to be typical of each of two methods of feeding, each of two main floor arrangements, and each of two types of patient service. It was decided to limit the initial study to two floors in order to ensure proper attention and training for a smaller study. The time of the members of the management society was limited, and it was felt that a small successful study would be of more value than complete coverage without proper opportunity for supervision of the study. Training of observers and the defining of categories was done as a joint effort of the staff and the management society men.

The categories decided upon were as follows:

1. Accompany doctor on rounds
2. Work on patient charts
3. Other paper work
4. Medication
5. Preparing food and checking diet slip
6. Serving food
7. Treatment of patients
8. Personal care of patients other than treatment

9. Not on floor
10. Telephoning
11. Instruction of student nurses
12. Supervision of personnel other than nurses
13. Cleaning rooms and making beds
14. Admitting or discharging patients
15. Conversation
16. Other activity
17. Walking

After three days' observation, a general discussion of the study was held with the nurses and the director of the study. The nurses felt that the categories might be expanded so that the category Preparing Food and Checking Diet Slips would be separated into two categories. In this way, the time for each of these activities could be measured. The activities differed in that one is manual, and the other clerical. In addition, new methods of serving food were planned. This separation was made, and Checking Diet Slips was designated as category 18. The nurses volunteered the information that taking observations was not burdensome. It was decided not to include the first three days' observations in the regular study, not only because of the category change, but also because this time had been designated as training.

The study was started in earnest, and a total of 5,973 observations was obtained over a period of 5 weeks. Since hospital records were quite complete (almost *too* complete), no particular additional supporting data were needed. Number of admissions, type of patient, and a few other data were used to check back in the records to establish the fact that the period studied was typical.

The number of nurses varied throughout the study because (1) at night not as many registered nurses and special-duty nurses were on the floor and (2) special-duty nurses are

assigned to one patient, and the need for this service varies from day to day. The results of the study will be summarized in this discussion, but other breakdowns were made for hospital management. For instance, night activity was compared to day activity, and week-end activity to weekday activity. Further, an analysis was made of the reasons for the nurses' being absent from the floor. All this information was included in a formal presentation of the results of the study. This presentation was made to hospital management and nursing supervision in a joint meeting. The results of the study were as follows:

ALL OBSERVATIONS

Category	%
1. Accompany doctor on rounds	4.7
2. Work on patient charts	3.1
3. Other paper work	1.6
4. Medication	2.1
5. Preparing food	9.1
6. Serving food	6.0
7. Treatment of patients	3.4
8. Personal care of patients other than treatment	14.7
9. Not on floor	11.6
10. Telephoning	1.9
11. Instruction of student nurses	1.3
12. Supervision of personnel other than nurses	0.8
13. Cleaning rooms and making beds	9.5
14. Admitting or discharging patients	2.2
15. Conversation	7.7
16. Other activity	12.6
17. Walking	4.1
18. Checking diet slips	3.6
	100.0

Hospital management and the nurses felt that the following results in particular categories were of most significance:

1. The time spent in activity associated with patient feeding totaled 18.6 per cent. This was considered excessive. Also, the floor which served food in bulk required significantly more time for this activity than did the floor which served food in trays from the kitchen.

2. The 1.3 per cent of the time spent in instruction of student nurses was felt to be inadequate.

3. The procedure for obtaining drugs was felt to be unsatisfactory. Most of the time in the Not on Floor category was spent in going to the pharmacy to get drugs and medications.

4. Most of the Other Activity category was simply personal time. No conclusion was drawn from this other than that the nurses were not being rushed in over-all activity.

5. Paper-work activity did not seem to be excessive.

6. The nurses spent more time than was desirable in making beds and cleaning rooms.

Specific action was taken to remedy the undesirable conditions. The first program started was an analysis of all phases of feeding. The basic contribution of the study was to show that this took the largest part of the nurses' time. Also, the study indicated that bulk feeding was more demanding on the nurses than the use of trays prepared in the kitchen. Conventional process charts were used for further study.

Steps were taken to ensure that the student nurses were given more formal instruction. This activity had been allowed to "slip."

An investigation was started of the issue of drugs. A new method was planned by which the pharmacist would make regular rounds with a cart containing the more commonly used drugs.

The hospital administration felt that the objectives of the study had been met. A bench mark had been established against which progress could be measured. Improvement programs could be directed at those activities which had been shown to require excessive amounts of the nurses' time. Finally, this had been done with the assistance of the nurses, and everyone had participated in the program. The members of the assisting management society were also in a better

position to help, because factual information now was available. These results had been obtained at practically no cost, and without disturbing the professional relationship existing at the hospital.

The outstanding accomplishment of such studies, in the opinion of most who have done them, is that Work Sampling enables the placing of a cost figure on nonstandardized activity. The next step, of course, is to acquaint the professional personnel in charge of specifying the details of patient care with this cost. It then becomes a problem of determining whether or not the benefit derived from each activity is worth the cost. Finally, when this phase has been explored, a proposal to obtain the same result but by different methods usually is much better received. In other words, many hospital Work Sampling studies have resulted in a good statement of the problem, plus some indication of the most profitable areas for improvement. This in itself is a very worthwhile accomplishment.

Airline Reservation Office—Telephone Activity of Agents

This example is one that should be read with care. Not only does it demonstrate measurement in an indirect-labor situation, but also it is first-class evidence of the worth of the technique of Work Sampling. The write-up here will consist of a few explanatory remarks, followed by an inclusion of the report submitted to management of the airline.

Two explanatory remarks are necessary:

1. One of the purposes of the report was to explain Work Sampling to others in the company. The industrial engineering department was anxious to expand the use of Work Sampling. To do this, it was necessary to convince others that the technique is sufficiently precise. Therefore a comparison was made between Work Sampling results and the results of

continuous observation. Usually, we do not have the "actual" to serve as a standard of comparison.

2. The memo-motion camera mentioned is simply a motion-picture camera which is controlled to take pictures at less than the usual speed of 16 frames per second. This technique was originated by M. E. Mundel.*

This study was conducted under the direction of A. C. Seccia of American Airlines. The authors regard it as a first-rate example of the use of Work Sampling.

WORK SAMPLING
DETERMINING THE AVERAGE LENGTH OF AN INCOMING TELEPHONE CALL

The primary function of a group of agents in our Reservation's offices is to answer incoming telephone calls from potential customers. The nature and length of these calls vary considerably. In order to accurately forecast the workload in our offices, it is necessary to know not only the expected number of incoming calls but, in addition, the average length of a call. Combining these two statistics, we can then adjust the manpower to handle the workload.

In a recent study, for comparative purposes, the average length of a phone call was determined by two methods:

I. *Continuous Observation*—using a memo-motion camera, the monitor (observing board) board was photographed every second. By interpretation of the lamps lit on the board, at each agent position, it was possible to determine whether an agent was:

(*a*) Talking on an incoming call
(*b*) Talking on an outgoing call
(*c*) Available to accept an incoming call
(*d*) Seated at his position but not ready or able to accept a call.

Through this continuous observation of agent activity, the average length of a call was determined by hour of the day and for the entire period of study.

II. *Work Sampling*—using the standard technique of work sampling,

* M. E. Mundel, "Motion and Time Study: Principles and Practice," 2d ed., chap. 14, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1955.

i.e. random observations, the average length of a call was determined for the same periods.

The procedure followed was:

1. An estimate of the percent of time agents spend handling incoming calls was made by substitution in the following:

$$p' = \frac{V \times H}{A \times 60} = \frac{\text{talking time}}{\text{available time}}$$

where V = estimated average hourly incoming telephone volume for the period to be studied

H = estimated average length of an incoming phone call (in minutes)

A = number of agents available for duty in the average hour

60 = number of minutes in an hour

2. The sample size required was determined:
   (a) Using the percent estimated in Step 1, the total sample size required was determined. Since the average length of a call is an important statistic in determining the workload, a small standard error was desired with a confidence level of 95%.
   (b) The total sample size was divided by the number of agents on duty in the average hour to determine the number of observation tours required.
   (c) The total number of observation tours was divided by the number of hours to be studied to determine the required number of observation tours per hour.

   The actual starting times of each observation tour was determined from a table of random numbers.

3. The observations were recorded on a form identical with that of Fig. 18-1. As the observer passed each agent position, he would record the activity of each agent at the precise moment of passing.

   Prior to starting the study, the various activities in which the agent could be engaged were determined to be:
   (a) Talking on an incoming call
   (b) Talking on an outgoing call
   (c) Waiting to accept an incoming call

(d) Available to accept an incoming call but finishing some clerical details of a previous call (this clerical work could be deferred if an incoming call should arrive)

(e) Seated at his position but unable to accept an incoming call (generally doing non-deferrable clerical work).

CITY NYC
DATE 10/21/55

Daily Observation Record

OBSERVER ____
SHEET # 1 OF 3

Observation No.	Time	Agents Talking: On Incoming Calls (1)	Agents Talking: On Outgoing Calls (2)	Agents Available: Waiting for an Incoming Call (3)	Agents Available: Doing Deferable Clerical Work (4)	Agents Not Available for Calls (5)	Total: Columns (1)(3)(4) (6)	Total: All Columns
1	9:21	卌 卌 卌 卌 卌 卌 |||	|			卌		
2	31	卌 卌 卌 卌 卌 卌 卌 卌		||	||	||||		
3	45	卌 卌 卌 卌 卌 卌 卌 ||	|	||	|	卌		
4	52	卌 卌 卌 卌 卌 卌 卌		||||	|||	卌 ||||		
5	59	卌 卌 卌 卌 卌 卌 卌 卌 |	|	||		卌 ||		
TOTAL	–	186	3	10	6	30	202	235
6	10:11	卌 卌 卌 卌 卌 卌 卌		卌 卌	||||	卌 卌		
7	22	卌 卌 卌 卌 卌 卌		卌 |||	卌 ||	卌 |||		
8	35	卌 卌 卌 卌 卌 卌 卌 |||				卌 卌 卌 |		
9	43	卌 卌 卌 卌 卌 卌 卌 卌 ||||		|		卌 ||||		
10	56	卌 卌 卌 卌 卌 卌 卌 卌 ||		|||		卌 |||		
TOTAL		189	–	22	11	52	222	274
11	11:04	卌 卌 卌 卌 卌 卌	||	卌 |||	||	卌 |||		
12	21	卌 卌 卌 卌 卌 卌 卌				卌 |||		
13	35	卌 卌 卌 卌 卌 卌 ||	|||			||||		
14	45	卌 卌 卌 卌 卌 卌 ||	||||			卌 ||		
15	55	卌 卌 卌 卌 卌 卌 卌 ||		|		卌 ||		
TOTAL		166	9	9	2	34	177	220
16	12:05	卌 卌 卌 卌 卌 卌 卌 ||				卌 |		
17	14	卌 卌 卌 卌 卌 卌 卌	||			卌 ||		
18	23	卌 卌 卌 卌 卌 |		卌 ||	||	卌 |||		
19	29	卌 卌 卌 卌 ||	|||	卌 |||	|	卌 |		
20	49	卌 卌 卌 卌 ||||	||	卌		卌 ||		
TOTAL		144	7	20	3	34	167	208

Fig. 18-1

4. The individual observations were summarized into hourly totals (Fig. 18-2) and the average length of call was computed for each hour and for the entire period of study.
5. The standard error was determined.

Hourly Summary of Observations

Average Length of an Incoming Call:

CITY________

DATE________

Hour	No. of Observation Tours (1)	Total Talking on Incoming Calls (2)	Total All Agents (3)	% Talking of Total (2)÷(3) (4)	Average No. of Agents per Observation (3)÷(1) (5)	Hourly Incoming Volume (6)	Average Length of Call: Elapsed Time x (4) x (5) / (6) (7)
0800-0859							
0900-0959	5	186	235	.791	47.0	769	2.90 minutes
1000-1059	5	189	274	.690	54.8	580	3.92 minutes
1100-1159	5	166	220	.755	44.0	526	3.78 minutes
1200-1259	5	144	208	.692	41.6	382	4.51 minutes
1300-1359	5	114	157	.726	31.4	355	3.85 minutes
1400-1459	5	158	189	.836	37.8	570	3.33 minutes
1500-1559	5	190	246	.772	49.2	557	4.10 minutes
1600-1659	5	144	204	.706	40.8	504	3.44 minutes
1700-1759	5	110	147	.748	29.4	373	3.54 minutes
1800-1859							
1900-1959							
2000-2059							
2100-2159							
2200-2259							
2300-2359							
Daily Total	45	1401	1880	.745	41.8	4616	3.65 minutes

FIG. 18-2

Comparison of Results

The chart below, which compares the average length of call as determined by Work Sampling with the average obtained by continuous observation, demonstrates the remarkable success we have had with the former tool. In spite of the fact that the sample size was based on the daily average per cent and there were wide variations in the hourly percentages, the hour by hour results of the two methods are comparable.

In addition to the high degree of accuracy obtained for the average length of call, Work Sampling has enabled us to obtain needed additional information about agent activity.

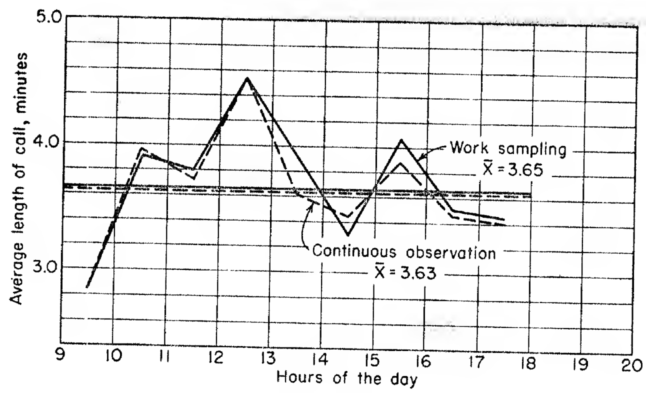

Fig. 18-3

For example, when we make our observations at the monitor board, it is impossible to tell whether an agent is actually waiting for an incoming call or finishing up some clerical work when the light indicates his position available. This is an important statistic because we train our agents to finish the clerical details (which would be of a deferrable nature) within the length of an incoming call. If the agents are not accomplishing this, a need for additional training is indicated. Analysis of the numbers or percentages in the other columns would reveal other needs or requirements.

Many applications of Work Sampling have been tried and proven successful in our Reservations and Ticket Offices. Work Sampling is one of our most frequently used methods of collecting data.

New York, N.Y.
March, 1956

AVERAGE LENGTH OF AN INCOMING CALL

1. Estimated per cent of time (p') agents talk on incoming call:
   V = 450 estimated average hourly phone volume.
   H = 4 minutes—estimated average call length.
   A = 40 expected number of agents on duty in the average hour.

$$p' = \frac{V \times H}{A \times 60} = \frac{450 \times 4}{40 \times 60} = \frac{1800}{2400} = 75\%$$

2. Sample size required:
   (a) p' = estimated per cent = 75% = .75
   y = allowable margin of error = $\pm 3\%$ = $\pm .03$
   $\sigma_{p'}$ = standard error = yp' = .03 × .75 = $\pm .0225$
   To achieve a confidence level of 95% $\sigma_{p'}/2$ = .01125

$$N = \frac{p'(1 - p')}{\sigma_{p'}^2} = \frac{.75\ (.25)}{(.01125)^2} = \frac{.1875}{.000127} = 1476 \text{ total sample size}$$

   (b) 1476 = total sample size required.
   40 = expected number of agents on duty in the average hour.

$$\frac{1476}{40} = 36.9 \text{ observation tours required}$$

   (c) 36.9 = observation tours required.
   9.0 = hours to be covered during study.

$$\frac{36.9}{9.0} = 4.1 \text{ observation tours per hour}$$

NOTE: 4.1 rounded to 5 observation tours per hour

3. Computation of Standard Error
   $\bar{p}$ = .745
   $1 - \bar{p}$ = .255
   N = 1880

$$\sigma_{\bar{p}} = \sqrt{\frac{p(1 - p)}{N}} = \sqrt{\frac{.745(.255)}{1880}} = \sqrt{.0001}$$

$$\sigma_{\bar{p}} = .01 = 1\%$$
$$2\sigma_{\bar{p}} = .02 = 2\%$$

$\bar{p} = .745$
$\bar{p} + 2\sigma_{\bar{p}} = .765$
$\bar{p} - 2\sigma_{\bar{p}} = .725$

Therefore, limits are within the allowable margin of error, i.e. $\pm 3\%$. Returning to the formula in paragraph 1 above and substituting the derived $\bar{p}$ and solving for H yields an average call length of 3.65 minutes, with upper and lower 95% limits of 3.75 and 3.55 minutes, respectively.

Work Sampling Bibliography

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Motion Pictures

"Work Simplification in Action." A 10-minute, 16-mm. sound film. Shows follow-up after initial conference. Factory work. Wolverine Tube Division, Calumet & Hecla, Inc., Detroit 9, Mich.

"The Ratio Delay Study—A New Tool of Work Simplification." A 10-minute, 16-mm. sound film. Shows general approach to ratio delay study and improvements resulting from ratio delay (Work Sampling) by participation of supervision. Wolverine Tube Division, Calumet & Hecla, Inc., Detroit 9, Mich.

"Work Sampling Demonstration." A 20-minute, 16-mm. sound film. Audience participation in demonstration of Work Sampling technique. Wolverine Tube Division, Calumet & Hecla, Inc., Detroit 9, Mich.

"Introduction to Work Sampling." A 19-minute, 16-mm. sound film. An aid to explaining Work Sampling. Loaned by Department of Visual Instruction, University Extension, University of California, Los Angeles 24, Calif.

Appendix 1. Random Sampling Numbers*

90	78	82	54	47	20	83	80	10	41	35	22	23	03	98	79	74	41	35	05	78	73	95	47	83
78	58	68	87	41	11	08	81	29	89	71	23	10	01	79	25	06	00	45	80	64	70	95	34	29
51	42	21	03	88	20	05	35	93	00	68	12	09	55	09	36	54	95	22	82	48	30	09	56	87
93	15	07	60	86	67	37	94	24	35	82	44	19	92	96	21	84	29	04	29	83	32	05	10	48
27	12	31	66	62	09	54	17	31	23	27	30	37	36	79	75	50	39	57	12	67	23	22	09	33
79	44	83	55	47	96	50	93	56	82	58	16	35	18	87	64	08	22	47	93	86	43	43	30	17
89	73	43	91	03	57	91	35	40	64	13	61	94	37	16	09	93	96	25	87	30	23	42	54	31
29	30	90	00	58	15	99	93	33	67	80	08	59	21	66	13	54	56	85	25	05	32	03	52	52
97	33	17	26	25	04	73	18	10	05	34	40	32	65	07	28	68	29	31	97	89	57	95	55	16
07	15	44	92	47	28	50	93	03	53	37	70	19	68	59	95	39	87	90	46	98	64	46	24	71
82	50	35	50	80	23	67	81	25	02	83	08	12	70	00	25	31	33	80	06	19	86	14	59	27
59	21	86	16	30	27	85	16	26	34	50	15	87	22	69	71	36	95	90	76	90	99	79	63	21
04	19	60	33	05	29	02	33	74	56	38	84	21	07	35	93	54	70	18	47	14	62	75	45	02
96	91	44	09	94	06	89	50	88	83	82	50	11	82	51	30	68	91	06	28	86	65	17	45	20
31	71	03	53	38	94	02	52	72	15	44	49	53	42	43	00	36	97	67	64	12	27	46	00	18
03	70	22	67	59	98	10	64	68	08	79	06	89	48	41	85	72	10	87	24	96	04	20	68	00
08	45	79	46	89	74	73	67	60	15	70	37	61	44	07	67	89	81	54	26	57	17	63	27	74
37	80	05	75	64	48	51	68	68	27	71	75	45	32	27	76	35	26	58	88	67	74	48	90	94
90	63	56	69	37	19	74	48	63	31	52	36	84	40	66	72	66	03	41	87	65	29	12	36	64
22	69	38	02	88	89	71	43	01	87	41	79	42	99	29	41	08	47	32	19	45	29	59	69	90
05	79	69	67	64	36	14	82	65	26	40	51	63	42	48	85	48	34	12	04	33	26	52	26	52
48	91	53	03	82	64	24	06	31	03	97	44	82	24	89	88	48	66	54	10	41	27	09	11	61
94	64	97	27	25	62	23	94	40	54	56	32	97	78	90	58	86	41	75	19	42	90	85	36	68
15	85	82	52	08	52	96	26	92	88	93	11	03	23	52	78	23	57	85	43	53	90	42	22	22
09	81	37	66	56	99	08	59	19	48	29	69	21	64	95	12	08	15	24	45	59	25	22	76	96

43	83	99	02	76	12	16	45	52	66	35	70	93	09	52	75	40	34	35	62	65	42	27	20	59
31	98	09	80	62	75	26	64	57	26	46	41	47	90	97	99	46	10	51	42	73	28	98	89	91
81	35	42	62	84	37	02	59	78	16	17	96	05	71	39	88	05	34	05	92	22	43	89	66	89
97	95	56	39	75	65	47	61	86	33	14	88	55	33	69	70	87	79	94	46	17	61	72	27	01
37	63	35	93	23	17	30	14	51	51	17	28	21	74	67	12	11	57	19	27	38	70	73	82	92
39	22	96	00	48	52	49	62	09	40	08	30	27	54	70	96	06	52	12	80	36	12	38	68	05
61	29	84	34	51	60	19	77	82	16	64	45	02	27	04	65	55	90	95	04	20	39	29	96	28
38	84	18	10	29	19	09	66	06	78	37	09	60	50	21	52	72	01	52	70	29	65	05	37	16
64	29	48	04	08	55	72	25	25	77	54	26	27	24	39	66	67	06	40	00	99	35	70	69	58
64	02	32	99	63	62	42	89	32	20	81	14	08	40	45	22	15	37	49	38	96	51	19	08	27
13	83	39	51	30	31	49	94	83	66	02	50	95	18	98	58	84	90	58	81	00	40	91	12	46
83	30	90	09	35	41	12	87	93	66	85	96	20	65	34	23	13	05	41	01	91	48	95	59	45
46	63	53	97	63	18	86	37	56	20	35	62	66	11	37	30	91	89	97	51	64	78	06	95	65
54	43	40	02	41	55	70	52	96	87	02	82	61	21	88	60	65	98	42	09	03	61	20	83	01
27	18	65	62	01	97	45	79	51	37	74	47	20	11	48	97	93	73	86	50	46	61	95	01	24
45	42	16	13	20	34	51	08	71	52	39	17	71	39	84	97	27	72	49	42	81	62	32	87	22
35	92	97	02	34	93	32	95	81	13	92	05	40	70	95	71	66	61	24	08	77	32	73	66	79
60	55	35	57	24	52	95	84	90	64	38	39	72	70	17	98	42	85	96	67	41	11	83	17	78
43	17	21	09	60	58	86	12	31	11	66	61	43	96	00	93	97	00	15	20	37	96	73	56	63
07	85	74	58	28	38	74	68	32	61	87	14	71	83	47	90	11	96	70	08	67	04	34	46	08
33	00	29	08	87	42	59	40	24	97	44	99	13	56	87	95	02	47	97	89	23	51	45	37	83
97	14	00	42	23	72	03	19	02	41	11	23	36	98	32	19	91	42	03	58	62	23	74	45	06
68	58	32	80	82	40	49	71	83	37	93	49	99	60	72	88	14	26	88	95	48	69	35	40	63
39	87	38	16	06	82	92	62	32	75	67	64	50	49	39	29	55	53	92	97	04	48	60	53	90
37	73	01	84	87	42	88	30	93	75	01	18	34	73	30	28	44	28	18	01	00	38	26	38	57

* Reprinted from A. Hald, "Statistical Tables," John Wiley & Sons, Inc., New York, 1952.

Appendix 2

Directions for Use of Tables A and B

Tables A and B are designed for use with a desk calculator or a slide rule, in order to obtain quickly and accurately probability limits for any value of p, or $\bar{p}$, and for any given sample size from 31 to 5,000. Limits at either 95 or 99 per cent (approximately) may be derived from these tables.

Table A contains values of the expressions $2\sqrt{p(1-p)}$ and $3\sqrt{p(1-p)}$ for values of p or $\bar{p}$ from 0.01 to 0.99, that is, from 1% to 99%. Table B contains the values of $\sqrt{n}$ for 240 different values of n from 31 to 5,000. Interpolation on a linear basis between any two consecutive values on either table will yield an approximately correct value for intermediate points not given in the tables.

The following examples show in detail some of the ways in which these tables may be used to assist in establishing limits in Work Sampling:

1. Given any p value, in per cent, to find 95 per cent confidence limits within which succeeding values of p, in per cent, should fall, assuming no change in the true value of p' during sampling, and assuming that random sampling conditions apply:

Assume: $p = 20$ per cent, or 0.20

$n = 200$

The upper control limit for p is

$$\mathrm{UCL}_p = p + \frac{2\sqrt{p(1-p)}}{\sqrt{n}} = 0.20 + \frac{0.8000}{14.14}$$
$$= 0.20 + 0.057 = 0.257 = 25.7 \text{ per cent}$$

The lower control limit for p is

$$\mathrm{LCL}_p = p - \frac{2\sqrt{p(1-p)}}{\sqrt{n}} = 0.20 - \frac{0.8000}{14.14}$$
$$= 0.20 - 0.057 = 0.143 = 14.3 \text{ per cent}$$

2. Given any p value, in per cent, to find 95 per cent confidence limits within which succeeding values of the quantity np should fall, assuming no change in the true value of p' during sampling, and assuming that random sampling conditions apply. In other words, given a p value equal to 20 per cent, and a sample of 200, np is equal to 40; this is the discrete number of observations or samples which fall into this category. To find limits, expressed in discrete units, proceed as follows:

$$\mathrm{UCL}_{np} = np + 2\sqrt{p(1-p)}\,(\sqrt{n}) = 40 + 0.8000(14.14)$$
$$= 40 + 11.31 = 51.31$$
$$\mathrm{LCL}_{np} = np - 2\sqrt{p(1-p)}\,(\sqrt{n}) = 40 - 0.8000(14.14)$$
$$= 40 - 11.31 = 28.69$$

Since in Work Sampling (and in most attribute sampling) we cannot have a fraction of an observation, 51 is the maximum number of observations which we could expect to occur by chance alone, and 29 is the minimum, since 28.0 would be below the limit.

3. Calculations similar to the above can be made, using 99 per cent confidence limits, by merely substituting the value of $3\sqrt{p(1-p)}$ in each equation for $2\sqrt{p(1-p)}$. In Example 1, above, using 99 per cent limits, UCL_p would become 0.285, or 28.5 per cent, while LCL_p would become 0.115, or 11.5 per cent. Similarly, in Example 2, above, UCL_{np} would be 56.97, or 56, and LCL_{np} would equal 23.03, or 24.

4. Given any value of $\bar{p}$, that is, the average of a number of successive values of p, to find the 99 per cent confidence limits within which all p values (used in computing $\bar{p}$) should lie,

assuming no change in the true value of p' during sampling, and assuming random sampling conditions applied:

Assume: $\bar{p} = 0.12$

20 successive samples, each having $n = 140$

$$\text{UCL}_p = \bar{p} + \frac{3\sqrt{\bar{p}(1-\bar{p})}}{\sqrt{n}} = 0.12 + \frac{0.9750}{11.83}$$
$$= 0.12 + 0.082 = 0.202, \text{ or } 20.2 \text{ per cent}$$
$$\text{LCL} = 0.12 - 0.082 = 0.038, \text{ or } 3.8 \text{ per cent}$$

5. Under the same assumptions and conditions as in Example 4, to find limits for np, that is, in discrete units:

$$\text{UCL}_{np} = n\bar{p} + 3\sqrt{\bar{p}(1-\bar{p})}\,(\sqrt{n}) = 16.80 + 0.9750(11.83)$$
$$= 16.80 + 11.53 = 28.33, \text{ or } 28$$
$$\text{LCL}_{np} = 16.80 - 11.53 = 5.27, \text{ or } 6$$

6. To find the 95 per cent limits for Examples 4 and 5, simply substitute the values of $2\sqrt{\bar{p}(1-\bar{p})}$ for $3\sqrt{\bar{p}(1-\bar{p})}$, wherever applicable.

7. Given the same data and assumptions as in Examples 4 and 5, above, to find 99 per cent confidence limits for $\bar{p}$, rather than for individual p values, that is, to determine the limits between which future values of $\bar{p}$ should fall, using a number of series of 20 samples of 140 each, so that n is equal to 2,800. This is the type of calculation which would be used, for example, to determine whether a significant change had or had not taken place in a certain p' during an interval in which no observations were made.

In terms of $\bar{p}$ in per cent:

$$\text{UCL}_{\bar{p}} = \bar{p} + \frac{3\sqrt{\bar{p}(1-\bar{p})}}{\sqrt{n}} = 0.12 + \frac{0.9750}{52.92}$$
$$= 0.12 + 0.018 = 0.138, \text{ or } 13.8 \text{ per cent}$$
$$\text{LCL}_{\bar{p}} = 0.12 - 0.018 = 0.102, \text{ or } 10.2 \text{ per cent}$$

In terms of $n\bar{p}$, or discrete units:

$$\begin{aligned} UCL_{n\bar{p}} &= n\bar{p} + 3\sqrt{\bar{p}(1-\bar{p})}\,(\sqrt{n}) = 336 + 0.9750(52.92) \\ &= 336 + 51.6 = 387.6, \text{ or } 387 \\ LCL_{n\bar{p}} &= 336 - 51.6 = 284.4, \text{ or } 285 \end{aligned}$$

8. Given the same data and assumptions as in Example 7, above, to find 95 per cent confidence limits, simply substitute $2\sqrt{\bar{p}(1-\bar{p})}$ for $3\sqrt{\bar{p}(1-\bar{p})}$, wherever it appears.

Directions for Use of Table C*

Table C has been prepared to enable the user to predetermine the sample size necessary in order to achieve a given degree of precision in the estimate of a category proportion p. For example, it can be used to determine how large a total sample must be made in order to achieve an error no larger than ± 5 per cent around a single estimated $\bar{p}$ value of, say, 15 per cent. Also, this table can be used to determine the number of observations per sample which should be made to obtain a given error around a p value. Moreover, by interpolation where necessary, it assists in approximating a precision present in any p value obtained from a total sample falling between maximum and minimum values falling on the same line of Table C. The entire Table C is based upon the 95 per cent confidence limits.

The following are specific examples of its use:

1. Given, from preliminary observations, an approximate $\bar{p}$ of 15 per cent, or 0.15, what total sample must be taken in order to obtain a reliability of 95 per cent that the true value p' lies within 1 per cent of 15 per cent, i.e., from 14 to 16 per cent?

By reference to Table C, for $p = 0.15$, for a 95 per cent confidence limit of 0.01, we find $n = 5{,}100$. This means that at

* The authors are indebted to Prof. P. J. Thorsen, of Michigan State College, for the idea and some of the material contained in Table C.

TABLE A. VALUES OF $2\sqrt{p(1-p)}$ AND $3\sqrt{p(1-p)}$ FOR VALUES OF p FROM 0.01 TO 0.99

p, $\bar{p}$, p'		Confidence Limits		p, $\bar{p}$, p'		Confidence Limits	
		95% $2\sqrt{p(1-p)}$	99% $3\sqrt{p(1-p)}$			95% $2\sqrt{p(1-p)}$	99% $3\sqrt{p(1-p)}$
0.01	0.99	0.1990	0.2985	0.26	0.74	0.8772	1.3158
0.02	0.98	0.2800	0.4200	0.27	0.73	0.8880	1.3320
0.03	0.97	0.3412	0.5118	0.28	0.72	0.8980	1.3470
0.04	0.96	0.3920	0.5880	0.29	0.71	0.9076	1.3614
0.05	0.95	0.4358	0.6537	0.30	0.70	0.9166	1.3749
0.06	0.94	0.4834	0.7251	0.31	0.69	0.9250	1.3875
0.07	0.93	0.5102	0.7653	0.32	0.68	0.9330	1.3995
0.08	0.92	0.5426	0.8139	0.33	0.67	0.9404	1.4106
0.09	0.91	0.5724	0.8586	0.34	0.66	0.9474	1.4211
0.10	0.90	0.6000	0.9000	0.35	0.65	0.9540	1.4310
0.11	0.89	0.6258	0.9387	0.36	0.64	0.9600	1.4400
0.12	0.88	0.6500	0.9750	0.37	0.63	0.9656	1.4484
0.13	0.87	0.6726	1.0089	0.38	0.62	0.9708	1.4564
0.14	0.86	0.6940	1.0410	0.39	0.61	0.9756	1.4634
0.15	0.85	0.7142	1.0713	0.40	0.60	0.9758	1.4697
0.16	0.84	0.7332	1.0998	0.41	0.59	0.9836	1.4754
0.17	0.83	0.7512	1.1268	0.42	0.58	0.9872	1.4808
0.18	0.82	0.7684	1.1526	0.43	0.57	0.9902	1.4853
0.19	0.81	0.7846	1.1769	0.44	0.56	0.9928	1.4892
0.20	0.80	0.8000	1.2000	0.45	0.55	0.9950	1.4925
0.21	0.79	0.8146	1.2219	0.46	0.54	0.9968	1.4952
0.22	0.78	0.8286	1.2429	0.47	0.53	0.9982	1.4973
0.23	0.77	0.8416	1.2624	0.48	0.52	0.9992	1.4988
0.24	0.76	0.8542	1.2813	0.49	0.51	0.9998	1.4997
0.25	0.75	0.8660	1.2990	0.50	0.50	1.0000	1.5000

TABLE B. VALUES OF n AND $\sqrt{n}$

n	$\sqrt{n}$	n	$\sqrt{n}$	n	$\sqrt{n}$	n	$\sqrt{n}$	n	$\sqrt{n}$	n	$\sqrt{n}$
31	5.57	71	8.43	155	12.45	355	18.84	610	24.70	1050	32.40
32	5.66	72	8.49	160	12.65	360	18.97	620	24.90	1100	33.17
33	5.74	73	8.54	165	12.85	365	19.11	630	25.10	1150	33.91
34	5.83	74	8.60	170	13.04	370	19.24	640	25.30	1200	34.64
35	5.92	75	8.66	175	13.23	375	19.37	650	25.50	1250	35.36
36	6.00	76	8.72	180	13.42	380	19.49	660	25.69	1300	36.06
37	6.08	77	8.78	185	13.60	385	19.62	670	25.88	1350	36.74
38	6.16	78	8.83	190	13.78	390	19.75	680	26.08	1400	37.42
39	6.25	79	8.88	195	13.96	395	19.88	690	26.27	1450	38.08
40	6.32	80	8.94	200	14.14	400	20.00	700	26.46	1500	38.73
41	6.40	81	9.00	205	14.32	405	20.13	710	26.65	1550	39.37
42	6.48	82	9.06	210	14.49	410	20.25	720	26.83	1600	40.00
43	6.56	83	9.11	215	14.66	415	20.37	730	27.02	1650	40.62
44	6.63	84	9.17	220	14.83	420	20.49	740	27.20	1700	41.23
45	6.71	85	9.22	225	15.00	425	20.62	750	27.39	1750	41.83
46	6.78	86	9.27	230	15.17	430	20.74	760	27.57	1800	42.43
47	6.86	87	9.33	235	15.33	435	20.86	770	27.75	1850	43.01
48	6.93	88	9.38	240	15.49	440	20.98	780	27.93	1900	43.59
49	7.00	89	9.43	245	15.65	445	21.10	790	28.11	1950	44.16
50	7.07	90	9.49	250	15.81	450	21.21	800	28.28	2000	44.72
51	7.14	91	9.54	255	15.97	455	21.33	810	28.46	2100	45.83
52	7.21	92	9.59	260	16.12	460	21.45	820	28.64	2200	46.90
53	7.28	93	9.64	265	16.28	465	21.56	830	28.81	2300	47.96
54	7.35	94	9.70	270	16.43	470	21.68	840	28.98	2400	48.99
55	7.42	95	9.74	275	16.58	475	21.80	850	29.16	2500	50.00
56	7.48	96	9.80	280	16.73	480	21.91	860	29.33	2600	50.99
57	7.55	97	9.85	285	16.88	485	22.02	870	29.50	2700	51.96
58	7.62	98	9.90	290	17.03	490	22.14	880	29.67	2800	52.92
59	7.68	99	9.95	295	17.18	495	22.25	890	29.83	2900	53.85
60	7.75	100	10.00	300	17.32	500	22.36	900	30.00	3000	54.77
61	7.81	105	10.25	305	17.46	510	22.58	910	30.17	3200	56.57
62	7.87	110	10.49	310	17.61	520	22.80	920	30.33	3400	58.31
63	7.94	115	10.72	315	17.75	530	23.02	930	30.50	3600	60.00
64	8.00	120	10.95	320	17.89	540	23.24	940	30.66	3800	61.64
65	8.06	125	11.18	325	18.03	550	23.45	950	30.82	4000	63.25
66	8.12	130	11.40	330	18.17	560	23.66	960	30.98	4200	64.81
67	8.19	135	11.62	335	18.30	570	23.88	970	31.15	4400	66.33
68	8.25	140	11.83	340	18.44	580	24.08	980	31.31	4600	67.82
69	8.31	145	12.04	345	18.57	590	24.29	990	31.46	4800	69.28
70	8.37	150	12.25	350	18.71	600	24.49	1000	31.62	5000	70.71

TABLE C. SAMPLE SIZES REQUIRED FOR VARIOUS LIMITS OF ERROR. 95 PER CENT CONFIDENCE LIMITS

p	Sample Size Required for Confidence Limits at 95%					p
	±0.01	±0.02	±0.03	±0.04	±0.05	
0.01	396*	100*	44*	25*	16*	0.99
0.02	784	196*	88*	49*	32*	0.98
0.03	1,163	292	130*	73*	47*	0.97
0.04	1,535	384	171	96*	62*	0.96
0.05	1,900	475	212	119	76*	0.95
0.06	2,260	565	252	142	92*	0.94
0.07	2,604	654	290	163	102	0.93
0.08	2,945	738	328	184	118	0.92
0.09	3,278	820	364	205	131	0.91
0.10	3,600	900	400	225	144	0.90
0.11	3,918	980	435	245	157	0.89
0.12	4,224	1,055	470	264	169	0.88
0.13	4,520	1,130	504	282	181	0.87
0.14	4,820	1,210	535	302	193	0.86
0.15	5,100	1,275	568	318	205	0.85
0.16	5,380	1,350	600	337	216	0.84
0.17	5,650	1,415	628	353	226	0.83
0.18	5,900	1,475	656	369	236	0.82
0.19	6,160	1,545	685	385	246	0.81
0.20	6,410	1,605	715	400	256	0.80
0.21	6,640	1,660	740	415	266	0.79
0.22	6,870	1,720	765	430	275	0.78
0.23	7,100	1,780	790	444	284	0.77
0.24	7,300	1,830	815	456	292	0.76
0.25	7,500	1,880	835	470	300	0.75
0.26	7,690	1,925	855	481	308	0.74
0.27	7,885	1,970	875	493	316	0.73
0.28	8,065	2,015	895	504	323	0.72
0.29	8,240	2,060	915	515	330	0.71
0.30	8,400	2,100	935	526	337	0.70
0.31	8,555	2,140	950	535	343	0.69
0.32	8,705	2,175	965	545	349	0.68
0.33	8,840	2,210	985	553	354	0.67
0.34	8,975	2,245	1,000	561	360	0.66
0.35	9,100	2,275	1,010	569	365	0.65
0.36	9,220	2,305	1,025	576	369	0.64
0.37	9,325	2,330	1,035	583	373	0.63
0.38	9,425	2,355	1,045	589	377	0.62
0.39	9,515	2,380	1,055	595	381	0.61
0.40	9,600	2,400	1,065	600	384	0.60
0.41	9,675	2,420	1,075	605	387	0.59
0.42	9,745	2,435	1,085	609	390	0.58
0.43	9,805	2,450	1,090	613	392	0.57
0.44	9,855	2,465	1,095	616	395	0.56
0.45	9,900	2,475	1,100	619	397	0.55
0.46	9,935	2,485	1,105	621	398	0.54
0.47	9,965	2,490	1,110	623	399	0.53
0.48	9,985	2,495	1,110	624	400	0.52
0.49	9,995	2,500	1,115	625	400	0.51
0.50	10,000	2,500	1,115	625	400	0.50

* Since, as a rule of thumb, np should equal 5 or more, the numbers followed by * should be increased to meet this criterion. For example, for p-0.03, n should be increased from 130 to 167, so that $0.03(167) = 5$.

least 5,100 observations must be made to ensure a p' of 14 to 16 per cent. Note here that if ± 3 per cent is desired, i.e., from 12 to 18 per cent, $n = 568$, or slightly more than one-tenth as large a sample!

2. Given a sample size of 180 observations per day, what precision would a single category per cent derived from this sample have? Or, restated, what confidence limits, at 95 per cent, could be placed on a Control Chart drawn so that each day's observations represented a single point on the Chart?

The answer to this question depends upon the proportion p that is obtained in the sampling, using $n = 180$. For example, if $\bar{p} = 0.13$, the 95 per cent confidence limits would be set at ± 0.05, that is, samples having p values from 8 to 18 per cent could be expected to occur by chance alone. Again, if $\bar{p} = 0.08$, the confidence limits would be placed at ± 0.04, or from 4 per cent as a lower limit to 12 per cent as an upper limit.

3. Given a p of 0.22, $n = 850$, what is the range within which p' lies, using the 95 per cent confidence limits?

From Table C, for $p = 0.22$, we find that $n = 850$ lies between ± 0.02 and ± 0.03. By linear interpolation (which is not quite correct, but is usually sufficiently close for purposes of Work Sampling),

$$0.02 + \frac{1{,}720 - 850}{1{,}720 - 765}(0.01) = 0.02 + \frac{870}{955}(0.01)$$
$$= 0.02 + 0.91(0.01) = 0.02 + 0.009 = 0.029$$

Therefore, the limits are approximately 0.22 ± 0.029, or from 0.191 to 0.249, that is, from 19.1 to 24.9 per cent.

Appendix 3

Areas under the Normal Curve

Proportion of total area under the curve that is under the portion of the curve from $-\infty$ to $\frac{X_i - \bar{X}'}{\sigma'}$. ($X_i$ represents any desired value of the variable X.)

$\frac{X_i - \bar{X}'}{\sigma'}$	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0.00
−3.5	0.00017	0.00017	0.00018	0.00019	0.00019	0.00020	0.00021	0.00022	0.00022	0.00023
−3.4	0.00024	0.00025	0.00026	0.00027	0.00028	0.00029	0.00030	0.00031	0.00033	0.00034
−3.3	0.00035	0.00036	0.00038	0.00039	0.00040	0.00042	0.00043	0.00045	0.00047	0.00048
−3.2	0.00050	0.00052	0.00054	0.00056	0.00058	0.00060	0.00062	0.00064	0.00066	0.00069
−3.1	0.00071	0.00074	0.00076	0.00079	0.00082	0.00085	0.00087	0.00090	0.00094	0.00097
−3.0	0.00100	0.00104	0.00107	0.00111	0.00114	0.00118	0.00122	0.00126	0.00131	0.00135
−2.9	0.0014	0.0014	0.0015	0.0015	0.0016	0.0016	0.0017	0.0017	0.0018	0.0019
−2.8	0.0019	0.0020	0.0021	0.0021	0.0022	0.0023	0.0023	0.0024	0.0025	0.0026
−2.7	0.0026	0.0027	0.0028	0.0029	0.0030	0.0031	0.0032	0.0033	0.0034	0.0035
−2.6	0.0036	0.0037	0.0038	0.0039	0.0040	0.0041	0.0043	0.0044	0.0045	0.0047
−2.5	0.0048	0.0049	0.0051	0.0052	0.0054	0.0055	0.0057	0.0059	0.0060	0.0062
−2.4	0.0064	0.0066	0.0068	0.0069	0.0071	0.0073	0.0075	0.0078	0.0080	0.0082
−2.3	0.0084	0.0087	0.0089	0.0091	0.0094	0.0096	0.0099	0.0102	0.0104	0.0107
−2.2	0.0110	0.0113	0.0116	0.0119	0.0122	0.0125	0.0129	0.0132	0.0136	0.0139
−2.1	0.0143	0.0146	0.0150	0.0154	0.0158	0.0162	0.0166	0.0170	0.0174	0.0179
−2.0	0.0183	0.0188	0.0192	0.0197	0.0202	0.0207	0.0212	0.0217	0.0222	0.0228
−1.9	0.0233	0.0239	0.0244	0.0250	0.0256	0.0262	0.0268	0.0274	0.0281	0.0287
−1.8	0.0294	0.0301	0.0307	0.0314	0.0322	0.0329	0.0336	0.0344	0.0351	0.0359
−1.7	0.0367	0.0375	0.0384	0.0392	0.0401	0.0409	0.0418	0.0427	0.0436	0.0446
−1.6	0.0455	0.0465	0.0475	0.0485	0.0495	0.0505	0.0516	0.0526	0.0537	0.0548
−1.5	0.0559	0.0571	0.0582	0.0594	0.0606	0.0618	0.0630	0.0643	0.0655	0.0668
−1.4	0.0681	0.0694	0.0708	0.0721	0.0735	0.0749	0.0764	0.0778	0.0793	0.0808
−1.3	0.0823	0.0838	0.0853	0.0869	0.0885	0.0901	0.0918	0.0934	0.0951	0.0968
−1.2	0.0985	0.1003	0.1020	0.1038	0.1057	0.1075	0.1093	0.1112	0.1131	0.1151
−1.1	0.1170	0.1190	0.1210	0.1230	0.1251	0.1271	0.1292	0.1314	0.1335	0.1357
−1.0	0.1379	0.1401	0.1423	0.1446	0.1469	0.1492	0.1515	0.1539	0.1562	0.1587
−0.9	0.1611	0.1635	0.1660	0.1685	0.1711	0.1736	0.1762	0.1788	0.1814	0.1841
−0.8	0.1867	0.1894	0.1922	0.1949	0.1977	0.2005	0.2033	0.2061	0.2090	0.2119
−0.7	0.2148	0.2177	0.2207	0.2236	0.2266	0.2297	0.2327	0.2358	0.2389	0.2420
−0.6	0.2451	0.2483	0.2514	0.2546	0.2578	0.2611	0.2643	0.2676	0.2709	0.2743

AREAS UNDER THE NORMAL CURVE (*Continued*)

$\frac{X_i - \bar{X}'}{\sigma'}$	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0.00
−0.5	0.2776	0.2810	0.2843	0.2877	0.2912	0.2946	0.2981	0.3015	0.3050	0.3085
−0.4	0.3121	0.3156	0.3192	0.3228	0.3264	0.3300	0.3336	0.3372	0.3409	0.3446
−0.3	0.3483	0.3520	0.3557	0.3594	0.3632	0.3669	0.3707	0.3745	0.3783	0.3821
−0.2	0.3859	0.3897	0.3936	0.3974	0.4013	0.4052	0.4090	0.4129	0.4168	0.4207
−0.1	0.4247	0.4286	0.4325	0.4364	0.4404	0.4443	0.4483	0.4522	0.4562	0.4602
−0.0	0.4641	0.4681	0.4721	0.4761	0.4801	0.4840	0.4880	0.4920	0.4960	0.5000
+0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
+0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
+0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
+0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
+0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
+0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
+0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
+0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
+0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8079	0.8106	0.8133
+0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
+1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
+1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
+1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
+1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
+1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
+1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
+1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
+1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
+1.8	0.9641	0.9646	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
+1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
+2.0	0.9773	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
+2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
+2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
+2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
+2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
+2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
+2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
+2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
+2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
+2.9	0.9981	0.9982	0.9983	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
+3.0	0.99865	0.99869	0.99874	0.99878	0.99882	0.99886	0.99889	0.99893	0.99896	0.99900
+3.1	0.99903	0.99906	0.99910	0.99913	0.99915	0.99918	0.99921	0.99924	0.99926	0.99929
+3.2	0.99931	0.99934	0.99936	0.99938	0.99940	0.99942	0.99944	0.99946	0.99948	0.99950
+3.3	0.99952	0.99953	0.99955	0.99957	0.99958	0.99960	0.99961	0.99962	0.99964	0.99965
+3.4	0.99966	0.99967	0.99969	0.99970	0.99971	0.99972	0.99973	0.99974	0.99975	0.99976
+3.5	0.99977	0.99978	0.99978	0.99979	0.99980	0.99981	0.99981	0.99982	0.99983	0.99983

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